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Durability Aspects of Rubbercrete Containing Nano Silica

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil)

MAY 2014

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CERTIFICATION OF APPROVAL

Durability Aspects of Rubbercrete Containing Nano Silica

By

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
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CERTIFICATION OF ORIGINALITY

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ABSTRACT

Environmental problem has been arising due to the unregulated disposal of waste tires. Most of the used tires are accumulated and stored in the shops or dumped at the landfill or dumping site. The growing problem of used tires creates major health and environmental problem and concern for the people as it is non-biodegradable. In recent researches, most of the experiments are conducted on utilizing recycled materials in construction sector to reduce the environmental impacts. Research work on crumb rubber produced from waste tires as a partial replacement of fine aggregates in concrete mixtures has been studied and results showed that crumb rubber concrete improves thermal, acoustic and electrical properties as compared to conventional concrete. However, the compressive strength of crumb rubber concrete decreases with the increasing percentage of crumb rubber. Addition of Nano silica in concrete will be effective in enhancing the durability of concrete. In this report, the main objective is to identify the durability of crumb rubber concrete containing Nano silica. The project work involved preparing concrete cubes with dimensions of 100mm x 100mm x 100mm using 0% - 5% of Nano silica. Tests conducted in this research include 28 days compressive strength test, Field Emission Scanning Electron Microscope (FESEM) and Mercury Intrusion Porosimetry (MIP). It has been found out that the crumb rubber concrete containing Nano silica improved the compressive strength, porosity and interfacial transition zone of the rubbercrete.

ACKNOWLEDGEMENT

The final year research project of “Durability aspects of rubbercrete containing Nano silica” is completed with the help and support from different people. Therefore, I would like to extend my appreciation to them on their endless contributions and support. Foremost, my deepest and sincerest gratitude to my final year project supervisor, AP. Dr. Bashar S Mohammed for the continuous support and guidance and for his patience, motivation, enthusiasm, and immense knowledge in the project. His guidance helped me in all the time of the research work and in writing of this thesis. His constructive comments and suggestions have contributed to the success of this project research.

Besides, I would also like to express my gratitude to the laboratory technician, Mr Johan, Mr Hafiz, Mr Ruzaimi, Mr Din, and Mr Anuar for their support and contribution on this project. During the laboratories work, I have been aided in preparing the sample and running the equipment. They have provides useful guidance and suggestion on preparing sample and collecting the data and results needed.

I would like to sincerely thank Universiti Teknologi Petronas for giving me the opportunity to carry out the final year project to improve my technical skills as well as management skills. These skills are very important for me during my working life and I have enhanced on my hand on skills, interpersonal skills and writing skills.

Last but not least, I would like to thank my family and friends for their unconditionally support and encouragement throughout my studies and research work. With the guidance and support from all the people, my research project has completed with great success.

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CHAPTER 1

INTRODUCTION

1.1. Background of the project

The production of waste tire rubber is estimated to reach 1.2 billion per year worldwide. Most of the used tires are accumulated and stored in the shops or dumped at the landfill or dumping site. Proper disposal of used tires are not provided or monitored. The growing problem of used tires create major problem and concern for the people as it is non-biodegradable. Discarded tires pose environmental problem and health hazard. They are dangerous when caught fire; it is very hard and even impossible to extinguish the fire. Figure 1 show the tire fire in Tracy California that burned for over two years. It is also an ideal breeding ground for mosquitoes, flies and other disease-carrying vectors.

Figure 1: A tire dump in Tracy California burned for over two years (Tire to Fuel, n.d.)

Many surveys and studied had been done in order to address the problem of reusing and recycling the discarded tires. One of them includes utilization of crumb rubber from this scrap tire as sustainable building materials in the construction industry helps preserve the natural resources and also maintain the ecological balance. (Mohammed et al., 2012). This is to incorporate recycled material such as crumb rubber in civil engineering application. Construction industry is believed to be one of the largest industries and the concrete will be dumped to the landfill after demolished which also creates major waste problem.

Crumb rubber is produced by shredding used tires and removing all the steels and fibres within it. Throughout the years, many researches and studies have been investigated and evaluated the partial replacement of crumb rubber for fine aggregate in the conventional concrete which is also known as rubbercrete. It is also proven that the replacement of crumb rubber as a partial replacement for fine aggregate in concrete block is a successful research. Crumb rubber concrete was found to have the following advantages:

i. Lightweight which has lower density,
ii. Better energy efficient which has lower thermal conductivity,
iii. Better acoustic properties which has higher noise reduction and lower sound absorption,
iv. Better electrical resistance which has higher electrical resistivity than conventional concrete,
v. As a load bearing concrete with compressive strength greater than $7N/mm^2$.

The utilization of crumb rubber as a partial replacement of fine aggregate in the concrete exhibits numerous benefits. However, the major problem of the crumb rubber concrete is the decrease of compressive strength with the increasing partial replacement of crumb rubber.

Nano particles nowadays are well recognised in many fields with their unique physical and chemical properties. Although Nano particles gain their popularity recently, they actually exist since the past decades. Nano particles are generally defined as particles with a diameter less than 100nm. (Hanus & Harris, 2013). Nano silica is in white powdery form (Figure 2) and due to its fine particles, the inhalation of Nano silica impose health hazard especially causing lung cancer. (Pacheco-Torgal & Jalali, 2011)

Figure 2: Nano silica sample (Jinsil700, n.d.)

Nano silica has recently gaining attraction in the civil engineering application with their distinct properties. Most of the studies reviewed that Nano silica has great potential in improving the compressive strength of concretes. The filler effects and pozzolanic reaction of Nano silica on concrete improved the durability and strength of the concrete. Besides, Nano size particles have a larger surface area to volume ratio that helps in speeding up the cement hydration and pozzolanic reaction.(Said et al., 2012). Crumb rubber concrete exhibits low compressive strength because of the weak bonding present between cement matrix and the crumb rubber particle. With the aid of Nano silica as filler, it react with calcium hydroxide to fill the voids of C-S-H and the microstructure in concrete is improved and become denser, thus the compressive strength of the crumb rubber concrete can be highly increased. (Rashad, 2014).

1.2. Problem Statement

The drawback of the crumb rubber concrete is the compressive strength of the crumb rubber concrete reduces significantly with increasing percentage of crumb rubber. The main reason for the decreasing compressive strength of crumb rubber concrete is due to the weak bonding between the cement matrixes with the crumb rubber. The bond strength is reduced as a result of the non-polarity properties of crumb rubber that repels water and entraps air on its surface. Therefore, an improvement is needed for this drawback to increase the compressive strength of the crumb rubber concrete. As a result, the interfacial transition zone between the cement matrix and the crumb rubber is enhanced by the usage of Nano silica (Nano SiO_2). The bond strength can be increased with the incorporation of Nano silica in concrete due to the pozzolanic reaction of Nano silica. The pozzolanic reaction of Nano silica convert calcium hydroxide from cement hydration to produce more C-S-H gel and the C-S-H gel will precipitate in the open available pores, leading to the formation of denser and more compact structure.

1.3. Objectives

The main objectives of this project are:

1. To establish the best dry-mix proportion for crumb rubber concrete containing Nano silica.

2. To determine the porosity of crumb rubber concrete containing Nano silica.

3. To evaluate the effects of Nano silica on the interfacial transition zone.

1.4. Scope of Study

In the research of “Durability Aspects of Rubbercrete Containing Nano Silica” project, the scope of study includes the following:

i. The average density of the all the materials used in fabricating the crumb rubber concrete is analysed in order to establish the dry-mix proportion needed by mixture for the fabrication of crumb rubber concrete. The materials involved in the density test includes cement, fly ash, fine aggregate, coarse aggregate, crumb rubber and Nano silica. The best dry-mix proportion for the fabrication of crumb rubber concrete is essential so that the best and most accurate results can be obtained.

ii. The ratio of cementitious material by volume for dry-mix concrete is tested by reducing the content of cement and replacing with 15% of fly ash in the mixtures. The replacement for fly ash is limited because over dosage of replacement may slower strength gain.

iii. The crumb rubber (10%, 25%, 50%) acts as a partial replacement for fine aggregate by volume in the fabrication of crumb rubber concrete. The replacement of crumb rubber is limited to 50% is mainly because the over dosage of replacement may reduce the compressive strength significantly.

iv. The Nano silica (Nano SiO_2) is added to improve the durability and performance of crumb rubber concrete. The weight addition of the Nano silica for this project is selected as 1%, 2%, 3%, 4%, and 5%.

v. The physical and mechanical properties test will be conducted for the crumb rubber concrete samples. The crumb rubber concrete samples will be tested for compressive strength test, mercury intrusion porosimetry test, and FESEM test.

CHAPTER 2

LITERATURE REVIEW

2.1. Environmental Problem of Tire Stockpiles

Due to industrial revolution and continual development of the countries around the world, rising amount of vehicles on the roads has generated millions of used tires each year. According to research, there will be approximately 1.4 billion tires sold annually throughout the world and eventually they will reach their end life span and categorized as used tires. (Presti, 2013). These 1.4 billion used tires produced annually subsequently require being disposed.

In some countries, the used tires are decomposed using combustion method but during the combustion process, huge amount of smoke are produced and reduce the environmental quality that causes pollution. The reduction in environment quality and causing of pollution has been the valid reason for most of the countries forbidden the burning of tires by law. Hence, the used tires are disposed in the landfills or dumpsite which is buried underground. (Issa & Salem, 2013). Stockpiled of used tire are disposed and accumulated unregulated in landfills or dumpsites throughout the world at present. However, the landfill consumption of used tires is huge because of its large volume and non-biodegradable nature. Adding to it, the accumulation of waste tires in the landfill will create health and environmental hazard to the people. The discarded tire stockpiles provide potential breeding ground for vector-carrying insects and rodents. In environmental hazard wise, it is very difficult to extinguish once the stockpiles of tire caught fire and the tire fire may cause environmental quality problems. (Grayson et al., 2013).

Therefore, measures are provided to reduce the numbers of disposed tire. Material and design improvement are made on the tires to double and lengthen the life time for the tires and reuse of tires are practises. Producing a new material using a waste product is an effective recycling which can prolong its life span and it is suitable for disposed tire which is non-biodegradable. (Zega & Di Maio, 2011). In countries such as United States, Japan and Korea, recycling of tires are practises. Among the recycling practises to solve the health and environmental problem, the measures are using disposed tires in reefs and breakwaters, playground equipment, erosion control as a barriers and processing discarded tire into crumb rubber to be used in some products or produce a useful products. (Jang et al., 1998).

2.2. Introduction to Crumb Rubber

Vehicle tire is commonly made up of this three main constituents which are natural rubber and synthetic rubber (elastomeric compound), fabric and steel. The sidewall of the tire is mostly rubber with the reinforcement of fabric and steel that maintains and supports the framework of the tire. The tire comprised of different parts which are the tread, the body, side walls and the beads. Figure 3 shows the different detailed parts of the tire. (Presti, 2013).

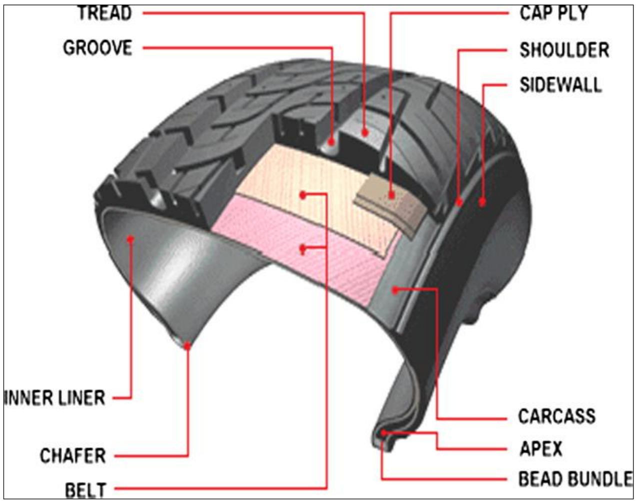


Figure 3: Detailed tire parts (Presti, 2013)

Crumb rubber is produced by shredding used vehicle tires and removing all the steel debris and fibres found within it. In general, vehicle tires can be shredded to crumb rubber by three ways which are cracker mill, granulator and micromill method. At the same time, cryogenation method can be used to shred the vehicle tire to crumb rubber. (Issa & Salem, 2013). The characteristics of crumb rubber from tire includes its ductility, light weight, elasticity and non-biodegradable properties, new markets with products made of crumb rubber are created. (Presti, 2013)

Construction has been a major and continuous emerging industry around the world. In construction industry, concrete is the most extensive used of material and once it is demolished for the development of the countries, it left with a huge disposal dumpsite of debris. The lacking of natural aggregates due to the excessive usage in fabricating the concrete as the primary constituents in concrete is problematic to the local authorities throughout the world. (Çakır, 2014). In order to address the problem, various alternatives in minimising and reducing the use of natural aggregates have been researched and studies. (Najim & Hall, 2010).Among them, utilization of crumb rubber to partially replace natural aggregates is one of the potential options. (Hosseini at al., 2011). However, utilization of crumb rubber in concrete will change the properties of concrete greatly. (Shu & Huang). Consequently, experiment and research on the crumb rubber to partially replace natural aggregates has been done.

2.3. Hardened Properties of Rubbercrete

Crumb rubber concrete with variety applications is being used in the construction industry to preserve natural resources and maintain the ecological balance for sustainable development. (Mohammed at al., 2012). Many experimental work and researches have been conducted to investigate the properties of concrete with addition of crumb rubber. Experiment done by Vadivel and Thenmozhi (2012) with a total of 108 specimens of cube, cylinder and beam were prepared using two different grade of concrete which is M20 and M25 and different percentage replacement of crumb rubber (0%, 2%, 4%, 6%, 8%, 10%) in replacing fine aggregate. From the experiment carried out, it is clearly indicated that when percentage of rubber replacement increases, the compressive strength decreases in both M20 and M25 grade concrete. Besides, higher grade of the concrete(M25) has higher compressive strength as compared to the concrete with lower grade (M20). The results proved that 6% replacement of waste tire rubber provides optimal replacement in concrete through excel in compressive, tensile and flexural strength. (Vadivel & Thenmozhi, 2012). Based on the results done in a similar study with different temperature tested and recycled aggregate used, maximum of 4% rubber content is optimal for limited strength decrease. (Guo at al., 2014).

Mohammed et al.(2011) evaluated the rubbercrete using non-destructive tests which are rebound hammer (RH) and ultrasonic pulse velocity (UPV). It is studied that when the percentage of crumb rubber concrete content increases, the UPV (Ultrasonic Pulse Velocity) values of the rubbercrete decreases. The UPV value can be influenced by many other factors which include air content and the nature of crumb rubber that entraps air on its surface. (Mohammed et al., 2011). The UPV value increases from 3days to 28 days because of the hydration of cement. Calcium silicate hydrate (C-S-H) is produced during the hydration that helps to fill the voids in the concrete. When the percentage of crumb rubber replacement increases, the rebound number decreases. However, the rebound number will increase with increasing curing days. It is mainly caused by the air content in the crumb rubber concrete as it absorbs more energy than the conventional concrete. Low water-cement ratio will increase the rebound number. (Mohammed et al., 2011).

Mohammed et al. (2012) focused on improving acoustic, thermal and electrical properties of hollow concrete block by partially replacing fine aggregate with crumb rubber. The result shows that the addition of fly ash and silica fume in crumb rubber concrete enhanced the compressive strength of hollow concrete block by creating better interfacial transition zone. Interfacial transition zones (ITZs) is a bond between the cement matrix and the aggregate particles. (Lee & Choi, 2013). However, the compressive strength reduces with the addition of crumb rubber percentage. The natural properties of crumb rubber entrapped the air on the surface of crumb rubber as it repels water during mixing. Crumb rubber hollow concrete block exhibits the properties of load-bearing, lightweight, low thermal conductivity, better sound absorption, and higher electrical resistivity as compared to conventional hollow concrete block. (Mohammed et al., 2012). Besides, crumb rubber concrete has better energy dissipation capacity and ductility as compared to conventional concrete. It is recommended to be used in seismic applications. (Son et al., 2011).

2.4. Fresh Properties of Rubbercrete

The slump test results done by Mohammed et al. (2012) show that when the percentage of crumb rubber increases, the slump value also increases. The main reason for the increase in slump value because of the increase in water-cement ratio which is caused by the non-polarity of crumb rubber that repels water and entraps air on its tough surface causes the water content in the rubbercrete mixtures increases. (Mohammed et al., 2011). Oven-dry density and specific gravity are studied for coarse aggregate, fine aggregate and crumb rubber. The specific gravity of the materials is calculated and it shows that the specific gravity of crumb rubber (0.95) as a replacement of fine aggregate is lower than fine aggregate (2.57) while the specific gravity of silica fume (2.27) as a replacement of cement is lower than cement (3.10). The reduction of specific gravity for the replacement material reduces the density of crumb rubber hollow concrete block. (Mohammed et al., 2012). As the crumb rubber possess a lower density than fine aggregate, the unit weight of crumb rubber concrete is reduced with an increase in water absorption and air content. (Naito et al.).

2.5. Nanotechnology in Concrete

Nanotechnology is introduced in the year of 1959 and later people explored the usage of the nanoparticles which is the core for cement phases and its high reactivity benefit helps to promote cement hydration. As Nano particles can help to create a denser microstructure and interfacial transition zone, it acts as filler and reduces the porosity and the presence of air void. (Sanchez & Sobolev, 2010). In the construction industry, concrete is one of the main constituent and studies show that approximately 3.3 billion tonnes of cement were produced in 2010 throughout the world. The upcoming developing and industrialised countries such as China and India is having increase demand on the production of cement for their continuous and constant growth. The production of cement has been increasing from 8% in 2009 worldwide and the increment will be rises from year to year in order to accommodate the mounting demand. (Hanus & Harris, 2013). However, production of cement has high energy consumption and produces carbon dioxide emissions which is opposes the standards for the green environment. The addition of Nano particles can improve the strength and durability aspects of the concrete and also reduce the carbon dioxide emissions from the production of cement. (Pacheco-Torgal & Jalali, 2011). Nano sized particles have a high surface area to volume ratio (Figure 4), thus provides tremendous chemical reactivity and it is very reactive. (Senff et al., 2012). Due to the advantages exhibit by Nano particles in concrete, the use of Nano particles in concrete has been a great issue lately. (Kong et al., 2013).

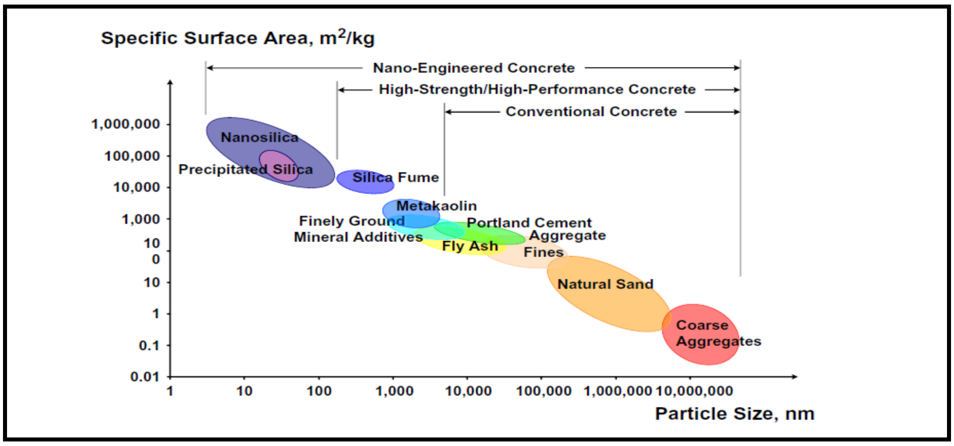


Figure 4: Particle size and specific surface area related to concrete materials (Sanchez and Sobolev, 2010).

Although all the nanoparticles are being tested and studied, most of the research works related to nanoparticles are focusing on Nano silica (nano-SiO2) and Nano titanium oxide (nano-TiO2). Nano silica has been found to improve concrete workability and strength, to increase resistance to water penetration and to help control the leaching of calcium. Also, Nano silica acts as filler to react with calcium hydroxide to produce higher amount of C-S-H that increase the durability and strength. (Senff et al., 2009).

Moreover, Nano silica was shown to accelerate the hydration reactions of both C_3S and an ash–cement mortar as a result of the large and highly reactive surface of the nanoparticles. (Sanchez & Sobolev, 2010).

2.6. Testing Method

2.6.1. Compressive Strength

The effects of Nano particles have been researched and the researchers found that Nano silica can accelerate the chemical reactions during initial hydration and strengthen the concrete structures. On top of it, Nano silica will react with calcium hydroxide and calcium hydroxide will generate the production of calcium silicate hydrate which leads to a denser microstructure. The mechanical properties such as compressive strength, flexural strength and abrasion resistance will be improving and decreases its permeability. (Senff et al., 2012). The addition of Nanoparticles in self-compacting concrete is recorded to improve the pore structure and hence strengthen the concrete. (Nazari & Riahi, 2011). Improvement on mechanical properties after addition of Nano silica is reported to be increased. The compressive strength, split tensile and flexural strength of 4% of Nano silica concrete is higher than the 0% Nano silica concrete after 28 curing days (Figure 5). (Hanus & Harris, 2013).

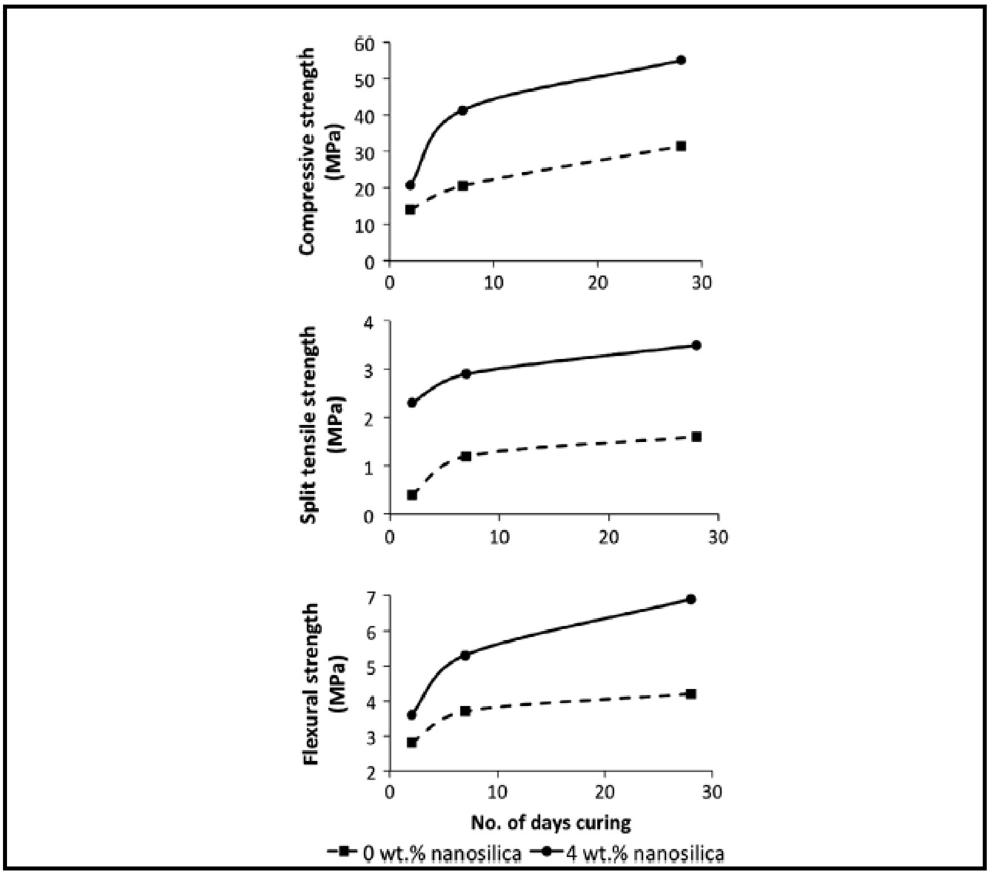


Figure 5: Strength assessment of self-compacting concrete after 2, 7 and 28 days of curing (Hanus and Harris, 2013).

The compressive strength of concrete containing Nano silica with granulated blast-furnace-slag is higher than normal concrete with the addition of granulated blast-furnace-slag. (Heikal et al., 2013). Recycled aggregates have disadvantages of low density, low durability and high water absorption. (Lee at al. 2013). To improve the shortcomings of the recycled aggregates, colloidal Nano silica is added into the mixture. The compressive strength of the concrete increases in 7 days with the incorporation of Nano silica resulted from the high pozzolanic action of Nano silica. In 28 days, the compressive strength of concrete increases due to the effects of Nano silica as a filler. (Mukharjee & Barai, 2014).

2.6.2. Field Emission Scanning Electron Microscope (FESEM)

Similar research about utilising Nano silica on recycled concrete is done but Hosseini et al. (2011) focused on the SEM (Scanning electron microscope) test where the test is to observe the interfacial transition zone between the cement paste and coarse aggregate. From the SEM (Scanning electron microscope) test, the figure 6, 7, 8, and 9 above clearly show that the transition zone of recycled concrete with addition of Nano silica has become denser and more uniform and even extremely small voids have been omitted. Nano silica will be enhancing the cementitious materials on producing the calcium-silicate-hydrate gel for a denser and uniform structure. (Hosseini et al., 2011).

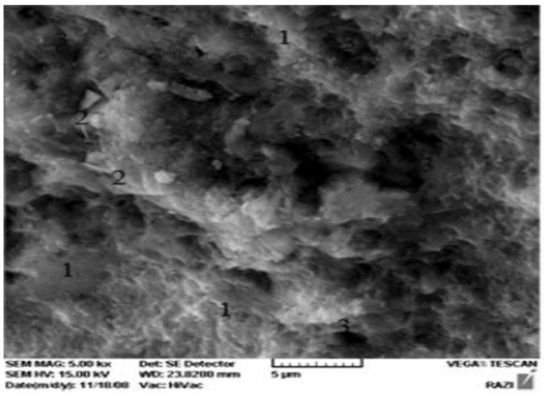


Figure 6: SEM results on the control mixture (Hosseini et al., 2011).

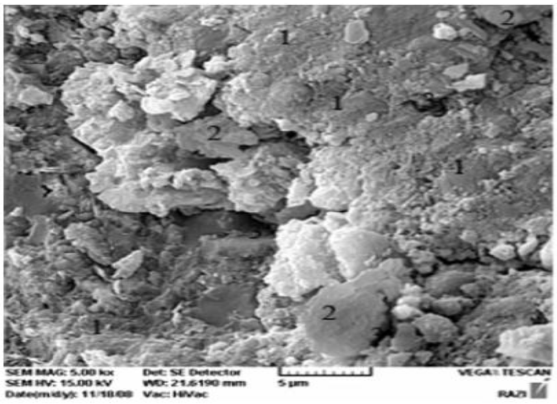


Figure 7: SEM results on recycled concrete (Hosseini et al., 2011).

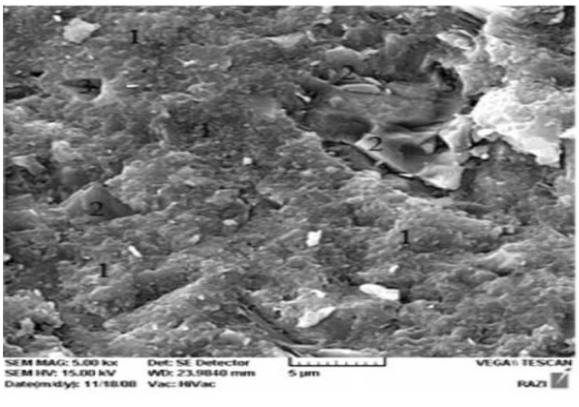


Figure 8: SEM results on recycled concrete(1.5% NS) (Hosseini et al., 2011).

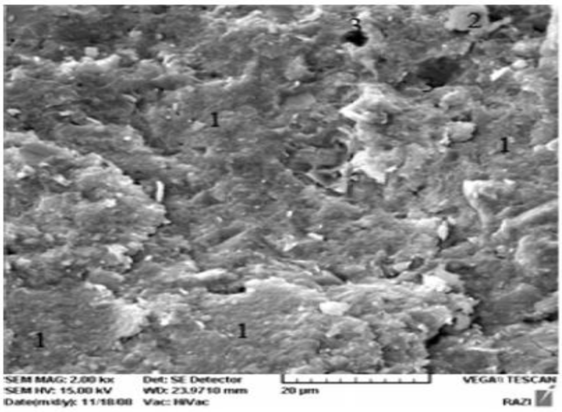


Figure 9: SEM results on recycled concrete (3% NS) (Hosseini et al., 2011).

2.6.3. Mercury Intrusion Porosimetry (MIP)

Studies done by Said et al. (2012) provide the influence of colloidal Nano-silica on concrete with cement and colloidal Nano-silica on concrete with cement and fly ash. Fly ash is used to reduce the cement content without affecting the properties significantly. (Fathifazl et al., 2009). Mercury Intrusion Porosimetry results showed that the total porosity and the threshold pore diameter were significantly lower for mixtures containing Nano silica. More refinement of the pore structure was achieved with increasing the Nano silica dosage up to 6%. Backscattered scanning electron microscopy analysis showed notable densification in the interfacial transition zone for specimens containing Nano silica. This suggests that the delay in microstructure development and durability improvement of concrete comprising Class F fly ash can be mitigated by the addition of small dosages of Nano silica. (Said et al., 2012).

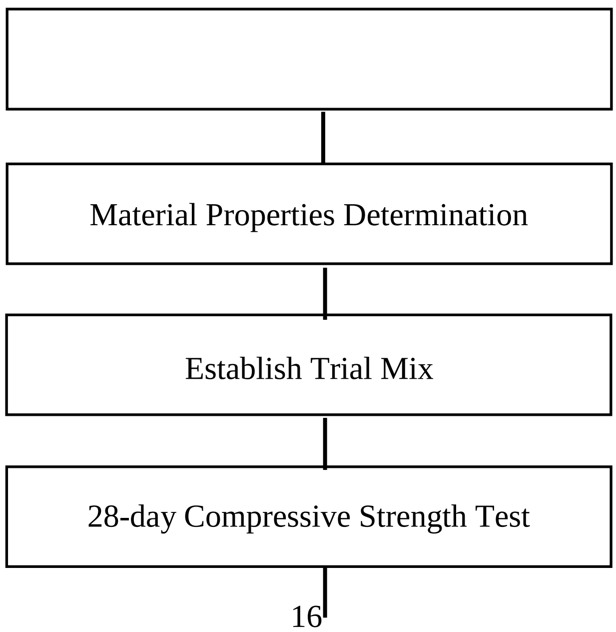
Study and Research on Topic

CHAPTER 3

METHODOLOGY

3.1. Project Methodology

The overall project flowchart is recorded in figure 10. Details of the project flowchart will be discussed in below.



Testing Procedure

Figure 10: Overall project flowchart

3.1.1. Study and Research on Topic

To have better understanding on the project, study and research on the topic is done thoroughly. Various journals and research papers are studied in order to investigate the problems and further improve on the shortcomings. Basic understandings on the materials and the preparation of the concrete sample are learnt and studied. Thorough literature reviews on the topic are very important to understand and prepare for the research work which includes studying on the method to prepare the sample for different testing, handling the equipment and collecting and analysing the data and results.

3.1.2. Material Properties Determination

The materials that are used in the manufacturing of crumb rubber concrete includes cement, fly ash, crumb rubber , fine aggregate, coarse aggregate and Nano silica. (Figure 11)

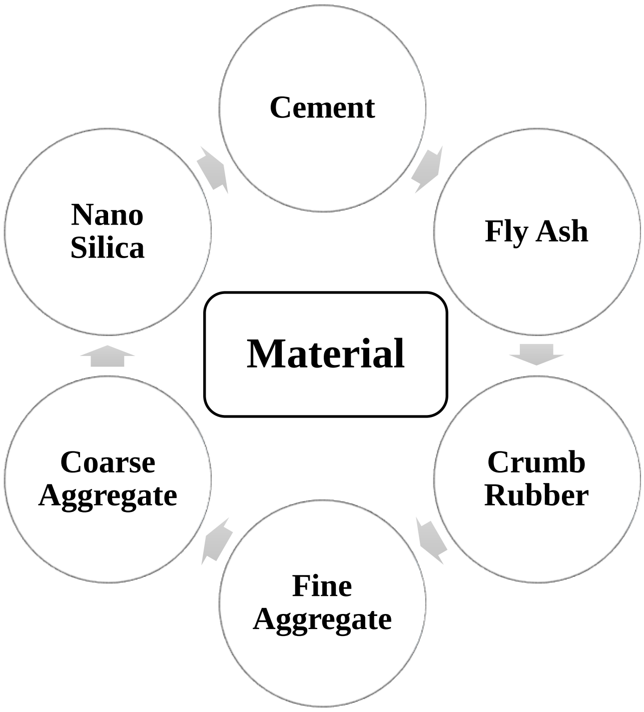


Figure 11: Materials for the mixture in fabricating rubbercrete containing Nano Silica

Density test for all the materials used in the mixture proportion are conducted in order to obtain the density of each material and the results are recorded in Table 1. The density for all the materials must be determined and known in order to establish the trial mix.

Table 1: Density for the material

Material	**Density (kg/m3)**
Coarse Aggregate	2.7539
Fly Ash	2.8839
Crumb Rubber	1.3536
Cement	3.3878
Sand	2.7528

3.1.3. Establish Trial Mix

The research work establish trial mix on S0F15 (silica fume 0%, fly ash 15%). The partial replacement of crumb rubber in each of the trial mixes are 0%, 10%, 25% and 50% and the addition of Nano silica is 0%-5% in each of the mixes. (Figure 12)

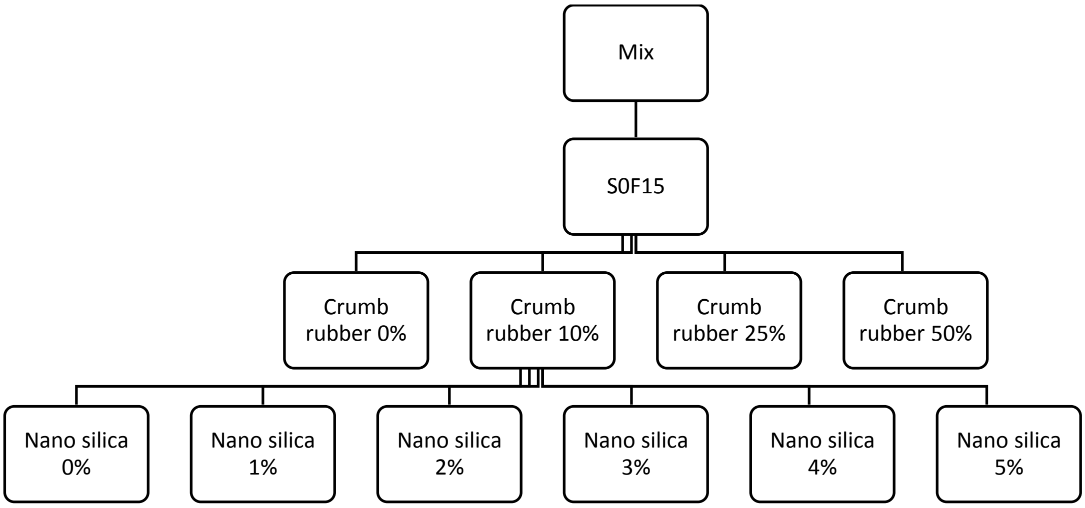


Figure 12: Summary on the mixture replacement

According to ASTM C90 and BS EN 771, the optimum replacement for crumb rubber is 50% to achieve the concrete block requirement. The example of mixture proportion for Nano silica 0% is calculated and tabulated in Table 2, 3, 4, and 5. As for mixture proportion from Nano silica 1% to 5% is recorded in Appendix 1. For each of the mixes, five cubes with dimensions of 100mm x 100mm x 100mm are produced for the testing. The laboratory works conducted as illustrated in Figure 13 include 28 days compressive strength test, Field Emission Scanning Electron Microscopy (FESEM), and Mercury Intrusion Porosimetry (MIP).

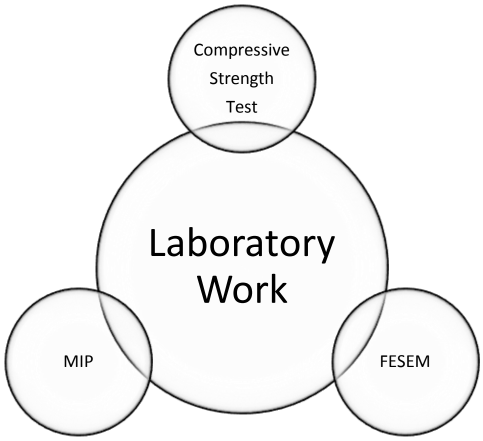


Figure 13: Summary of laboratory work

Table 2: Mixture Proportion for Nano Silica 0% Crumb Rubber 0%

Nano Silica 0% Crumb Rubber 0%	**per 1 mix(kg)**	**per 5 mix(kg)**
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.3764	6.882
Crumb Rubber	0	0
Nano Silica	0	0
Water	0.2314343	1.1571715

Table 3: Mixture Proportion for Nano Silica 0% Crumb Rubber 10%

Nano Silica 0% Crumb Rubber 10%	**per 1 mix(kg)**	**per 5 mix(kg)**
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.23876	6.1938
Crumb Rubber	0.06768	0.3384
Nano Silica	0	0
Water	0.2258375	1.1291875

Table 4: Mixture Proportion for Nano Silica 0% Crumb Rubber 25%

Nano Silica 0% **Crumb Rubber 25%**	**per 1 mix(kg)**	**per 5 mix(kg)**
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.0323	5.1615
Crumb Rubber	0.1692	0.846
Nano Silica	0	0
Water	0.2174423	1.0872115

Table 5: Mixture Proportion for Nano Silica 0% Crumb Rubber 50%

Nano Silica 0% **Crumb Rubber 50%**	**per 1 mix(kg)**	**per 5 mix(kg)**
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	0.6882	3.441
Crumb Rubber	0.3384	1.692
Nano Silica	0	0
Water	0.2034503	1.0172515

3.1.4. Preparation of Test Specimen

A total of 24 concrete cubes with dimensions of 100mm x 100mm x 100mm as shown in Figure 14 were produced for the laboratory works and testing. The compressive strength test cubes were prepared in accordance with the requirements of the BS EN 12390-2.

Figure 14: Concrete cubes sample

The concrete cubes were fabricated in steel moulds (Figure 15) using dry-mix method. Compaction was applied with 50 blows for each cube in order to compact the material in the mould equally as normal rod tamping method is not suitable for dry-mix method. The concrete cubes were removed after 24 hours and left for air-dry curing.

Figure 15: Steel moulds

After 28 days of curing, the concrete cubes were used for the laboratory testing. Different types of concrete cubes specimens are prepared according to the different testing requirements. Three concrete cubes are prepared for 28-days compressive strength tests and the remaining cubes are utilized for the Field Emission Scanning Electron Microscopy (FESEM), and Mercury Intrusion Porosimetry (MIP).

3.1.5. 28-day Compressive Strength Test

The compressive strength tests for the concrete cubes are performed in accordance with the requirements of ASTM C140. The compressive strength of rubbercrete are obtained using ELE ADR 3000kN compression machine (Figure 16). The compression machine is equipped with a 200mm x 200mm steel plate. The compression testing required even surface on the concrete or else capping will be needed for the concrete.

Figure 16: 3000kN compression machine

3.1.6. Testing Procedure

The Mercury Intrusion Porosimetry Test is the most popular test used for determining the pore characteristics in the concrete. The porosity test is conducted using Thermo Finnigan Pascal 240 (Figure 17) with a high pressure station up to 200MPa and pore radius analysis from 7.5 to 0.0037µm. It is used to measure the volume and size of pores.

Figure 17: Thermo Finnigan Pascal 240

Field Emission Scanning Electron Microscope (FESEM) with ultra-high-resolution imaging is designed to fulfil the requirements of analysing up to nano scale surface structure and morphology of solids. The results for FESEM test were obtained using SUPRA 55VP (Figure 18) manufactured by Carl Zeiss AG, Germany. The resolution is 4nm at 0.1kV and 0.8nm at 30kV.

Figure 18: SUPRA 55VP

CHAPTER 4

RESULTS AND DISCUSSION

4.1. 28-day Compressive Strength

Table 6 show the overall compressive strength test results for S0F15 mix after 28 days of curing. There are 24 trial mixes with Nano silica (1% - 5%) and rubber replacement (10%, 25%, and 50%). For Nano silica 0% and crumb rubber replacement of 0%, it acts as a control mix for the research.

Table 6: Overall results for 28 days compressive strength

Mix	Percentage of Nano Silica (%)	Percentage of Crumb Rubber (%)	Compressive Strength (N/mm^2)
S0F15	0	0	39.5
		10	23.9
		25	9.1
		50	0.8
	1	0	42.4
		10	35.5
		25	9.4
		50	1.1
	2	0	44.9
		10	36.3
		25	11.4
		50	1.5
	3	0	46.2
		10	36.6
		25	13.7
		50	2.2
	4	0	54.5
		10	43.1
		25	18.1
		50	3.1
	5	0	61.4
		10	44.5
		25	21.6
		50	8.1

In Figure 19, the compressive strength of rubbercrete is decreases with the increasing percentage of crumb rubber replacement after 28 days of curing. The decrement in compressive strength is caused by the hydrophobic nature of crumb rubber that repels water and entraps air on its surface. The air entraps on the surface of crumb rubber increases the air content in rubbercrete, creating a weak interfacial transition zone between crumb rubber and cement paste and thus, reducing the compressive strength of the rubbercrete. With the presence of crumb rubber, the adhesion of cement matrix with coarse aggregate is reduced. When the surface area of crumb rubber becomes higher, the adhesion between cement matrix and crumb rubber becomes lower as well as the compressive strength of rubbercrete. (Mohammed et al., 2012)

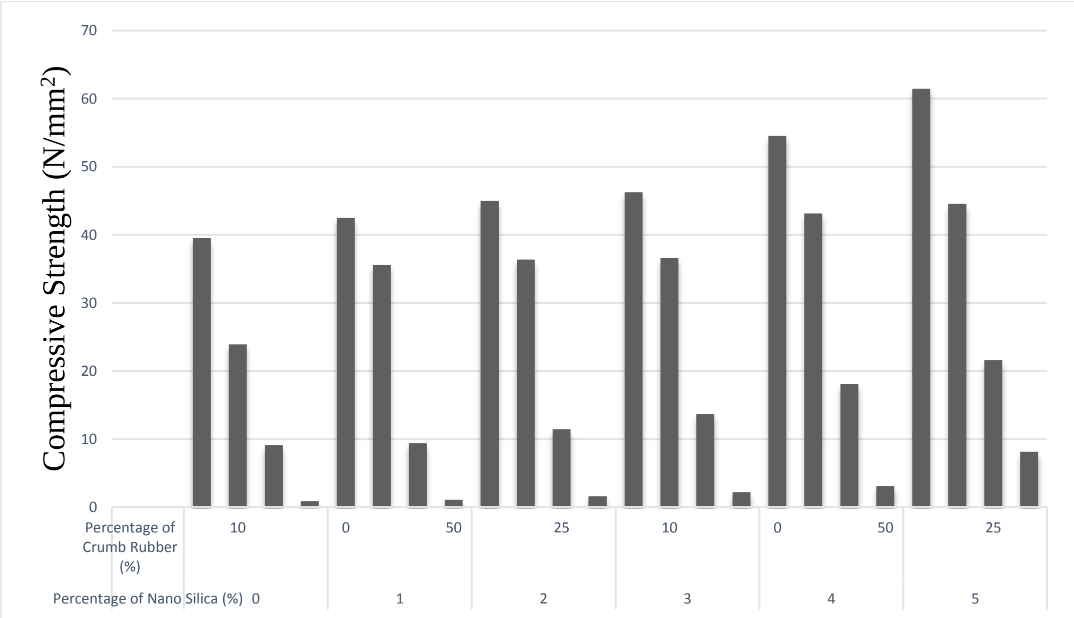


Figure 19: Graph of percentage of crumb rubber versus compressive strength

The compressive strength of rubbercrete can be enhanced by using Nano silica. From Table 6, the compressive strength of rubbercrete increases with the increasing percentage of Nano silica from 0% to 5%. For example, NS5 CR0 achieves the compressive strength of 61.423N/mm^2 which is higher than NS0 CR0 with compressive strength of 39.467/mm^2. The increase in the compressive strength after the addition of Nano silica in the mixture is due to the effect of Nano silica that acts as filler and has pozzolanic reaction with calcium hydroxide that fills the voids of calcium silicate hydrate (C-S-H) gel and reduces the volume of pores in the cement matrix. The increase in calcium hydroxide improves the microstructure of the concrete and interfacial transition zone between crumb rubber and cement matrix. The microstructure of concrete becomes denser and more compact with the addition of Nano silica in the rubbercrete. (Heikal et al., 2013)

4.2. Mercury Intrusion Porosimetry(MIP)

The porosity, total pore volume, total pore surface area and maximum pore diameter for the rubbercrete can be obtained using mercury intrusion porosimetry test. The results for the porosity, total pore volume, total pore surface area and maximum pore diameter of the rubbercrete are determined and tabulated in the Table 7.

Table 7: Porosity obtained from Mercury Intrusion Porosimetry (MIP)

Percentage of Nano Silica (%)	Percentage of Crumb Rubber (%)	Porosity (%)	Total pore volume (mm3/g)
0	0	9.9	23.6
	10	15.3	48.6
	25	24.2	79.1
	50	29.7	149.6
1	0	7.5	23.5
	10	11.8	44.2
	25	21.5	54.0
	50	26.6	140.7
2	0	6.8	22.4
	10	8.0	33.1
	25	12.9	50.7
	50	26.3	132.4
3	0	6.2	21.9
	10	6.5	27.1
	25	11.3	33.7
	50	24.5	110.1
4	0	5.9	21.1
	10	6.5	25.9
	25	9.6	33.5
	50	17.7	67.4
5	0	5.9	1.9
	10	1.4	-1.6
	25	7.7	29.7
	50	13.8	62.0

From Figure 20, the porosity of the rubbercrete increases with the increasing percentage of crumb rubber replacement. This is because the non-polarity of crumb rubber that repels water and entraps air on its surface which create air voids in between crumb rubber and cement matrix. The increase in the air void increases the porosity of the crumb rubber. The porosity of rubbercrete reduces with the addition of Nano silica because Nano silica acts as filler and has pozzolanic reaction with calcium hydroxide to fill the air voids present in the rubbercrete. The voids in the rubbercrete are filled and the pore appears in the rubbercrete is refined and reduced which resulting in decreasing of porosity.

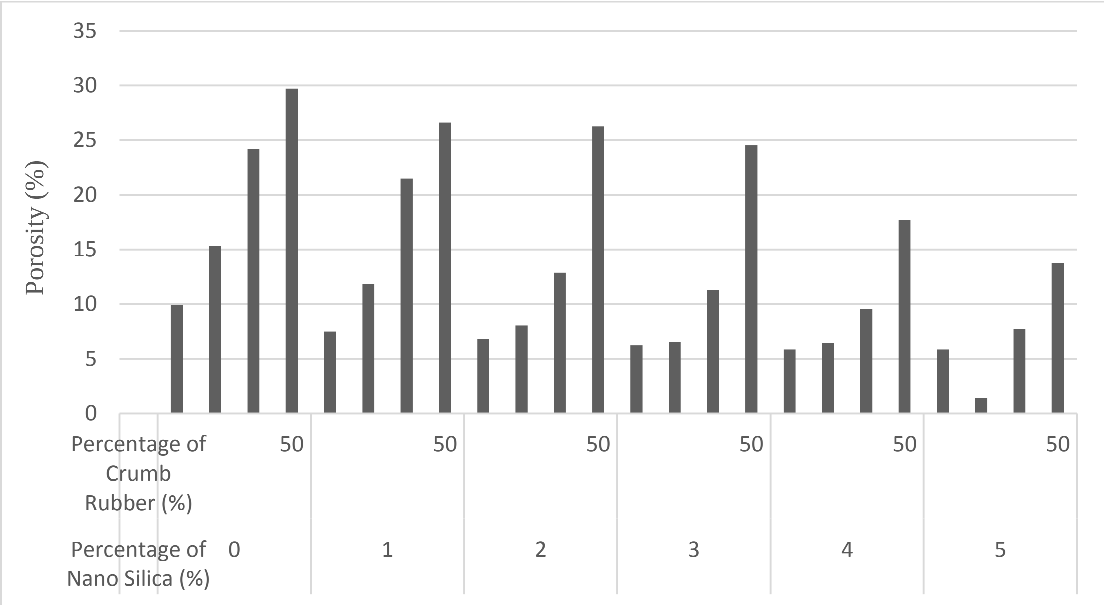


Figure 20: Graph represents porosity obtained from Mercury Intrusion Porosimetry (MIP)

Figure 21 illustrates the total pore volume of the rubbercrete with Nano silica 0% to 5% and percentage of crumb rubber replacement (0%, 10%, 25%, and 50%). Total pore volume increases with the increasing crumb rubber replacement but decreases with the addition of Nano silica. This is because increment of crumb rubber replacement increase the porosity of rubbercrete and addition of Nano silica reduces the porosity of the rubbercrete. With the increasing of porosity of the rubbercrete, the total pore volume of concrete also increases.

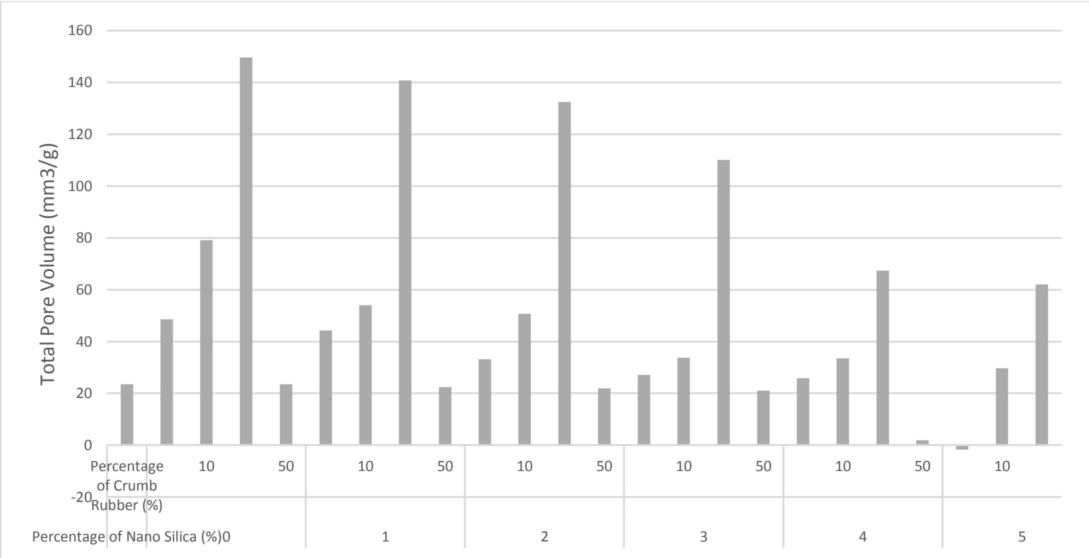


Figure 21: Graph represents total pore volume obtained from Mercury Intrusion Porosimetry (MIP)

4.2.1. Pore Size Distribution

4.2.1.1. Influence of Crumb Rubber on Rubbercrete

Figure 22, 23, 24, and 25 presented the graph of pore size distribution for Nano silica 0% with different percentage of crumb rubber replacement (10%, 25%, and 50%) and a control mixture which is NS0CR0. The pore diameter ranges from 10-100000nm in size. Table 8 below showed the total pore volume for the mixture.

Figure 22, 23 and 24, and 25 has a gradually decreasing distribution of the pore diameter. This showed that the increasing percentage of crumb rubber replacement not only increases the pore volume of the concrete, it also increases the volume of small pores as compared to the control mixture. The presence of air voids due to the replacement of crumb rubber increases the volume of small pores in the concrete. Higher pore volume in the pore size distribution represent that the mixture has higher porosity and permeability.

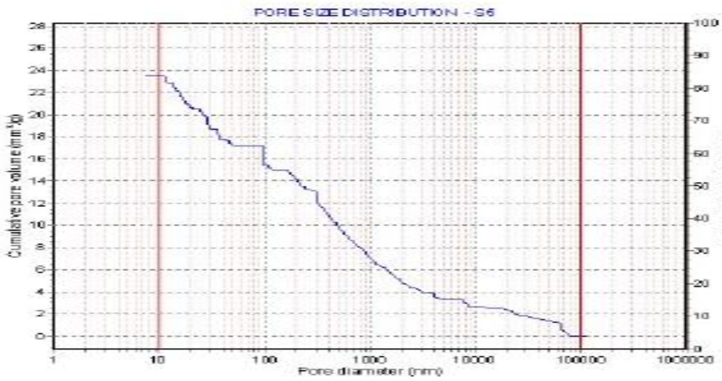


Figure 22: Pore size distribution for NS0CR0

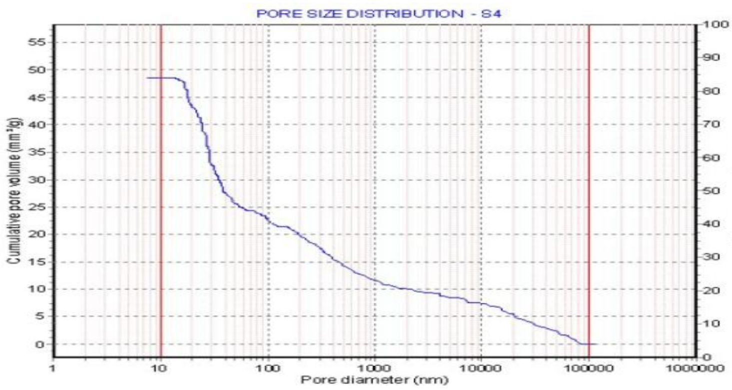


Figure 23: Pore size distribution for NS0CR10

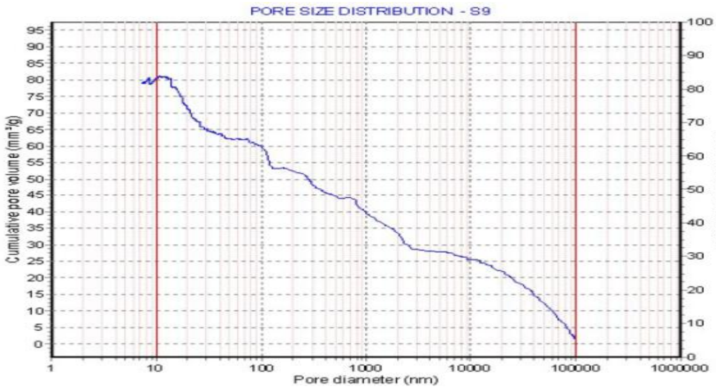


Figure 24: Pore size distribution for NS0CR25

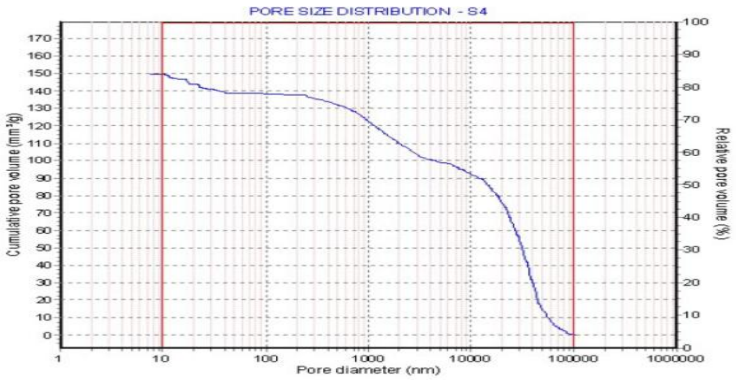


Figure 25: Pore size distribution for NS0CR50

From Table 8, the results showed that the total pore volume increases with the increasing percentage of crumb rubber replacement. The total pore volume is higher in mixture NS0 CR50 because of the replacement of fine aggregate with crumb rubber. The replacement of 50% crumb rubber is an outlier that has a total pore volume of 149.62mm^3/g. Crumb rubber tended to repel water and entraps air on the surface of the crumb rubber which led to the formation of air voids in the concrete. The presence of higher number of air voids increases the pore volume in the concrete. Higher percentage of crumb rubber replacement increases the number of air voids, resulting in increasing volume of pores.

Table 8: Total pore volume for Nano silica 0%

Mixture		Total pore volume (mm^3/g)
NS0	CR0	23.55
	CR10	48.59
	CR25	79.1
	CR50	149.62

Figure 26, 27, 28, and 29 presented the graph of pore size distribution for Nano silica 1% with different percentage of crumb rubber replacement (10%, 25%, and 50%) and a control mixture which is NS1CR0. The pore diameter ranges from 10-100000nm in size. Table 9 below showed the total pore volume for the mixture.

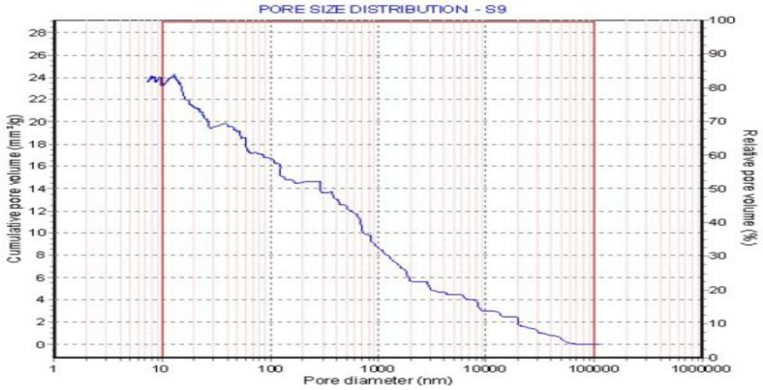


Figure 26: Pore size distribution for NS1CR0

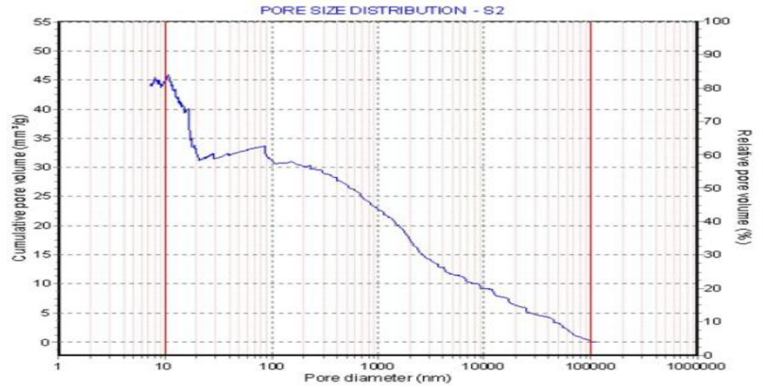


Figure 27: Pore size distribution for NS1CR10

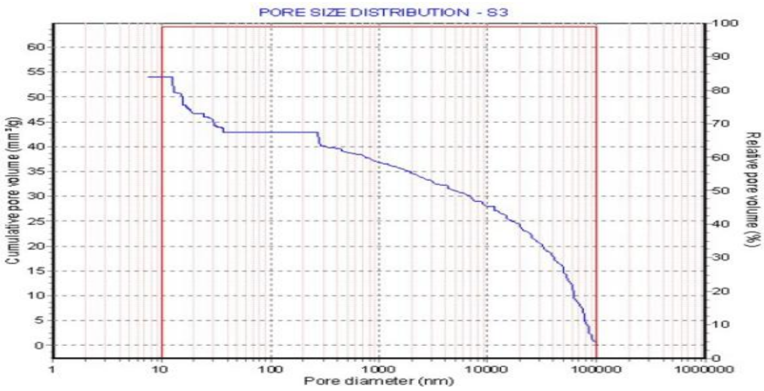


Figure 28: Pore size distribution for NS1CR25

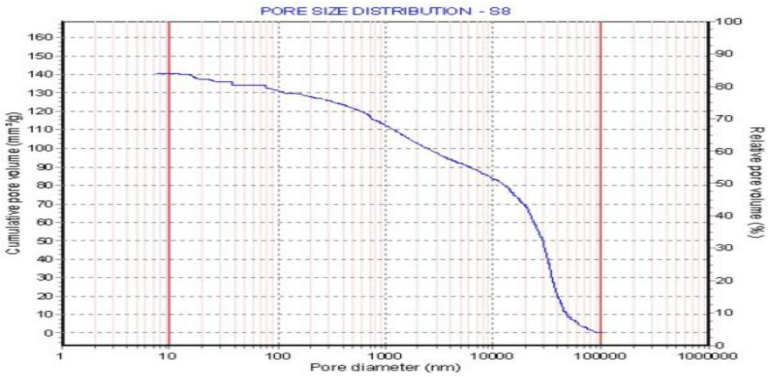


Figure 29: Pore size distribution for NS1CR50

From Table 9, the results showed that the total pore volume increases with the increasing percentage of crumb rubber replacement. The total pore volume is higher in mixture NS1 CR50 because of the replacement of fine aggregate with crumb rubber. The replacement of 50% crumb rubber is an outlier that has a total pore volume of 140.67mm^3/g. Crumb rubber tended to repel water and entraps air on the surface of the crumb rubber which led to the formation of air voids in the concrete. The presence of higher number of air voids increases the pore volume in the concrete. Higher percentage of crumb rubber replacement increases the number of air voids, resulting in increasing volume of pores. The pore distribution for Nano silica 1% has a gradually decreasing distribution of pore diameter. Higher pore volume in the pore size distribution represent that the mixture has higher porosity and permeability.

Table 9: Total pore volume for Nano silica 1%

Mixture		Total pore volume (mm^3/g)
NS1	CR0	23.53
	CR10	44.23
	CR25	54
	CR50	140.67

Figure 30, 31, 32, and 33 presented the graph of pore size distribution for Nano silica 2% with different percentage of crumb rubber replacement (10%, 25%, and 50%) and a control mixture which is NS2CR0. The pore diameter ranges from 10-100000nm in size. Table 10 below showed the total pore volume for the mixture.

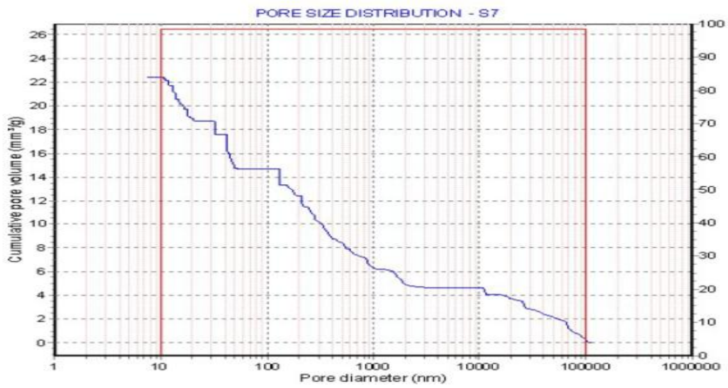


Figure 30: Pore size distribution for NS2CR0

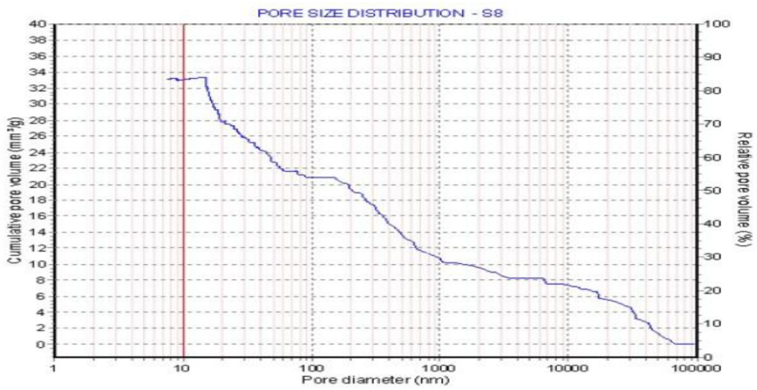


Figure 31: Pore size distribution for NS2CR10

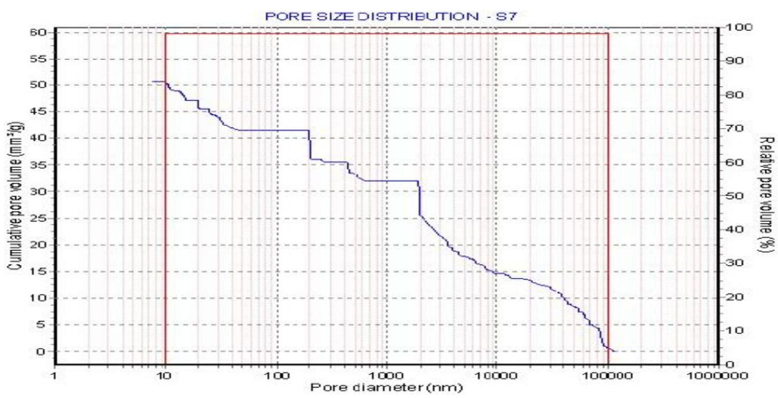


Figure 32: Pore size distribution for NS2CR25

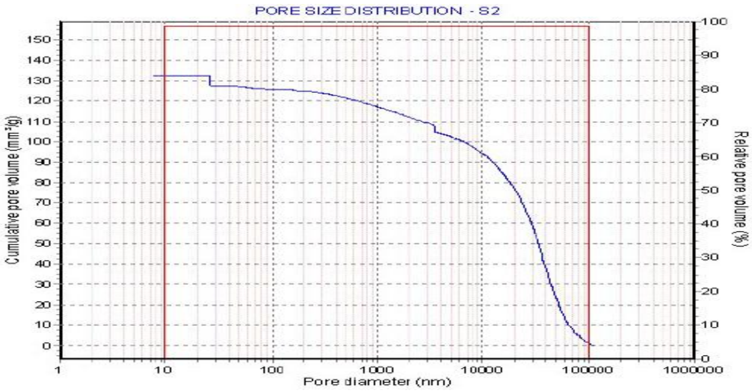


Figure 33: Pore size distribution for NS2CR50

From Table 10, the results showed that the total pore volume increases with the increasing percentage of crumb rubber replacement. The total pore volume is higher in mixture NS2 CR50 because of the replacement of fine aggregate with crumb rubber. The replacement of 50% crumb rubber is an outlier that has a total pore volume of 132.38mm^3/g. Crumb rubber tended to repel water and entraps air on the surface of the crumb rubber which led to the formation of air voids in the concrete. The presence of higher number of air voids increases the pore volume in the concrete. Higher percentage of crumb rubber replacement increases the number of air voids, resulting in increasing volume of pores. The pore distribution for Nano silica 2% has a gradually decreasing distribution of pore diameter. Higher pore volume in the pore size distribution represent that the mixture has higher porosity and permeability.

Table 10: Total pore volume for Nano silica 2%

Mixture		Total pore volume (mm^3/g)
NS2	CR0	22.44
	CR10	33.09
	CR25	50.73
	CR50	132.38

Figure 34, 35, 36, and 37 presented the graph of pore size distribution for Nano silica 3% with different percentage of crumb rubber replacement (10%, 25%, and 50%) and a control mixture which is NS3CR0. The pore diameter ranges from 10-100000nm in size. Table 11 below showed the cumulative pore volume for the mixture.

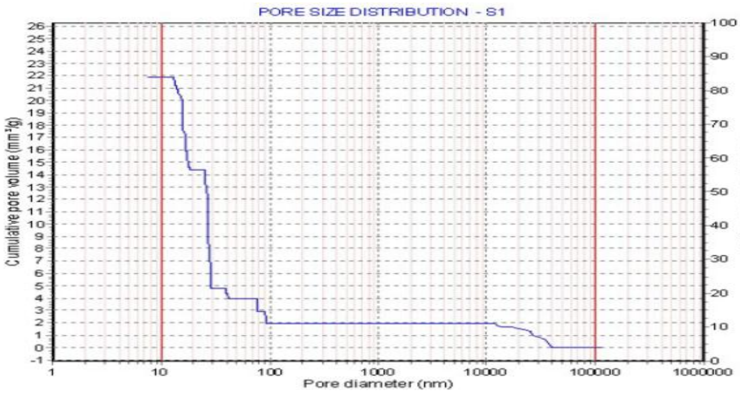


Figure 34: Pore size distribution for NS3CR0

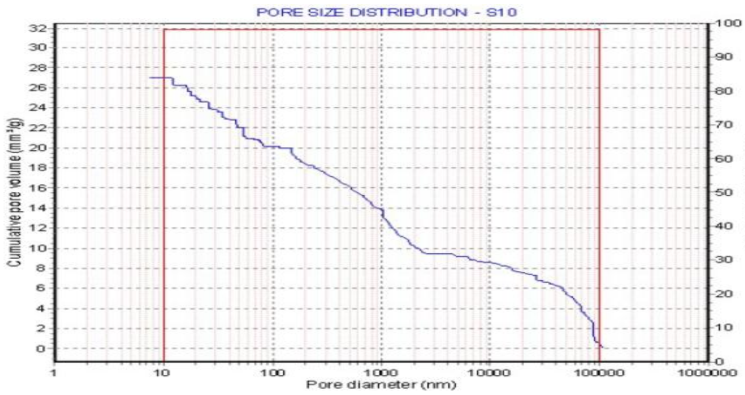


Figure 35: Pore size distribution for NS3CR10

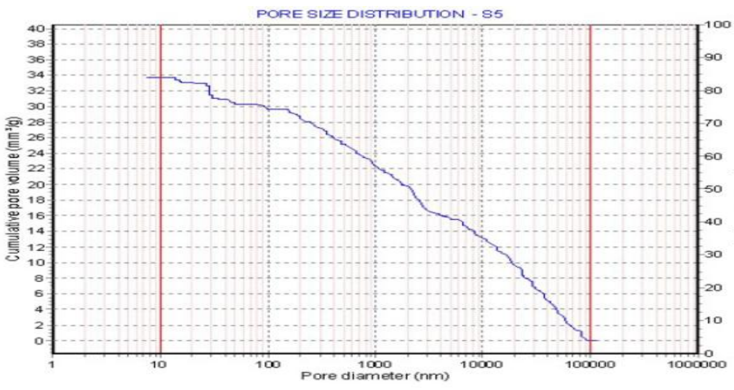


Figure 36: Pore size distribution for NS3CR25

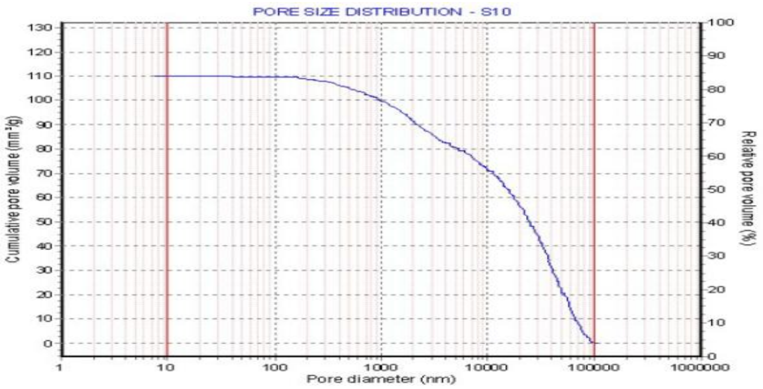


Figure 37: Pore size distribution for NS3 CR50

From Table 11, the results showed that the total pore volume increases with the increasing percentage of crumb rubber replacement. The total pore volume is higher in mixture NS2 CR50 because of the replacement of fine aggregate with crumb rubber. The replacement of 50% crumb rubber is an outlier that has a total pore volume of 67.37mm^3/g. Crumb rubber tended to repel water and entraps air on the surface of the crumb rubber which led to the formation of air voids in the concrete. The presence of higher number of air voids increases the pore volume in the concrete. Higher percentage of crumb rubber replacement increases the number of air voids, resulting in increasing volume of pores. The pore distribution for Nano silica 3% has a gradually decreasing distribution of pore diameter. Higher pore volume in the pore size distribution represent that the mixture has higher porosity and permeability.

Table 11: Total pore volume for Nano silica 3%

Mixture		Total pore volume (mm^3/g)
NS3	CR0	21.91
	CR10	27.05
	CR25	33.73
	CR50	110.05

Figure 38, 39, 40, and 41 presented the graph of pore size distribution for Nano silica 4% with different percentage of crumb rubber replacement (10%, 25%, and 50%) and a control mixture which is NS4CR0. The pore diameter ranges from 10-100000nm in size. The Table 12 below showed the total pore volume for the mixture.

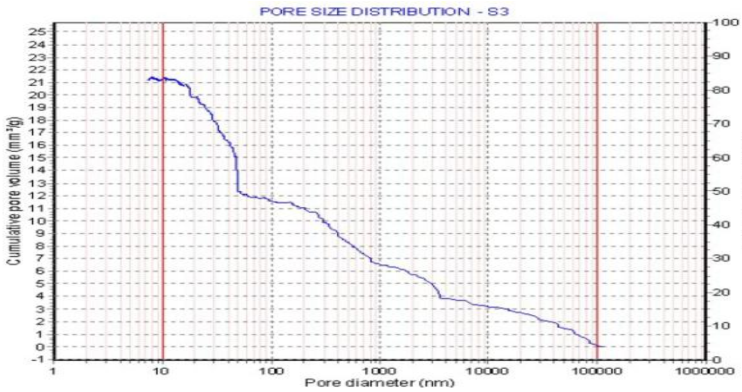


Figure 38: Pore size distribution for NS4CR0

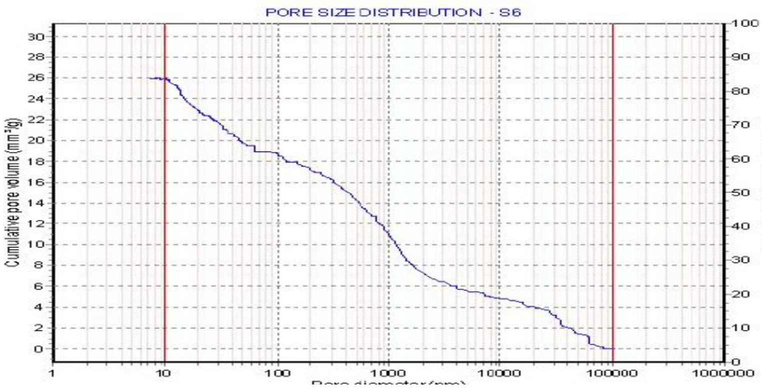


Figure 39: Pore size distribution for NS4CR10

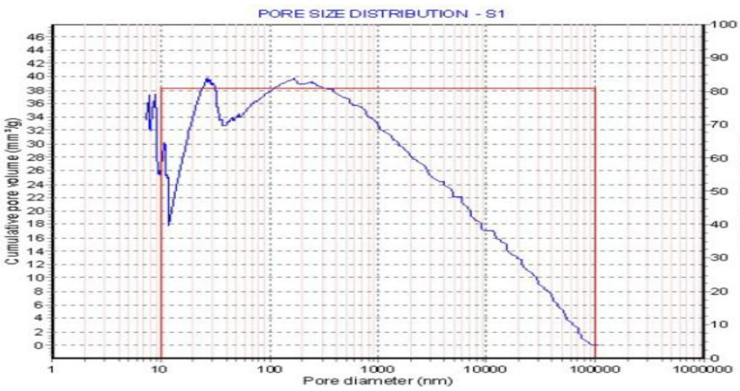


Figure 40: Pore size distribution for NS4CR25

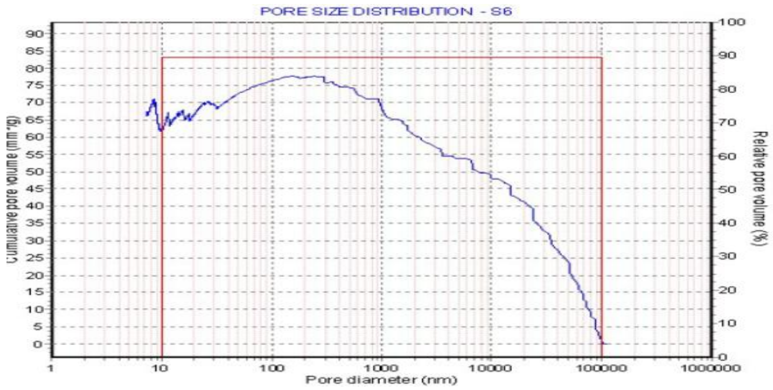


Figure 41: Pore size distribution for NS4CR50

From Table 12, the results showed that the total pore volume increases with the increasing percentage of crumb rubber replacement. The total pore volume is higher in mixture NS4 CR50 because of the replacement of fine aggregate with crumb rubber. The replacement of 50% crumb rubber is an outlier that has a total pore volume of 110.05mm^3/g. Crumb rubber tended to repel water and entraps air on the surface of the crumb rubber which led to the formation of air voids in the concrete. The presence of higher number of air voids increases the pore volume in the concrete. Higher percentage of crumb rubber replacement increases the number of air voids, resulting in increasing volume of pores. The pore distribution for Nano silica 4% has a gradually decreasing distribution of pore diameter. Higher pore volume in the pore size distribution represent that the mixture has higher porosity and permeability.

Table 12: Total pore volume for Nano silica 4%

Mixture		Total pore volume (mm^3/g)
NS4	CR0	21.11
	CR10	25.89
	CR25	33.49
	CR50	67.37

Figure 42, 43, 44, and 45 presented the graph of pore size distribution for Nano silica 4% with different percentage of crumb rubber replacement (10%, 25%, and 50%) and a control mixture which is NS5CR0. The pore diameter ranges from 10-100000nm in size. Table 13 below showed the total pore volume for the mixture.

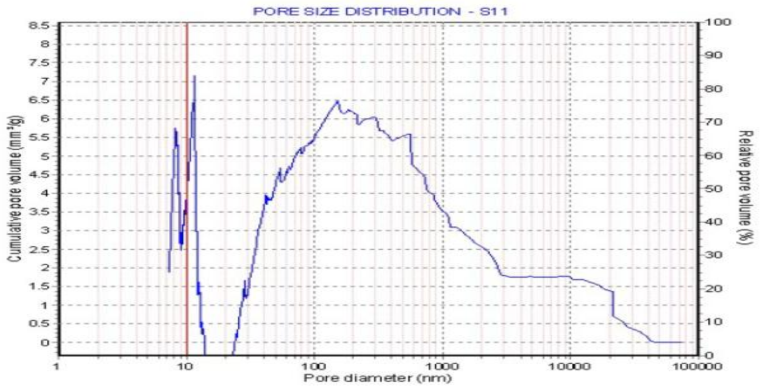


Figure 42: Pore size distribution for NS5CR0

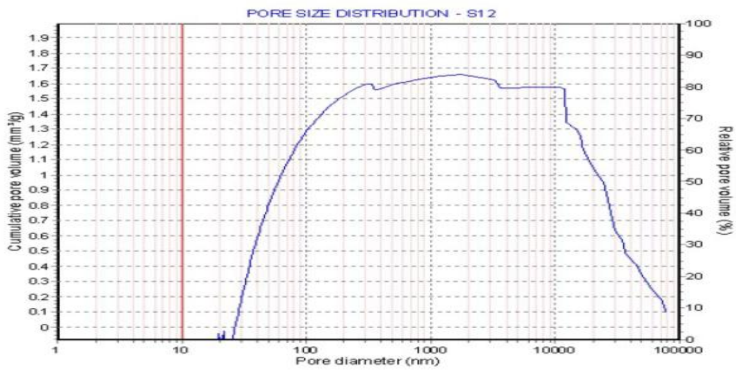


Figure 43: Pore size distribution for NS5CR10

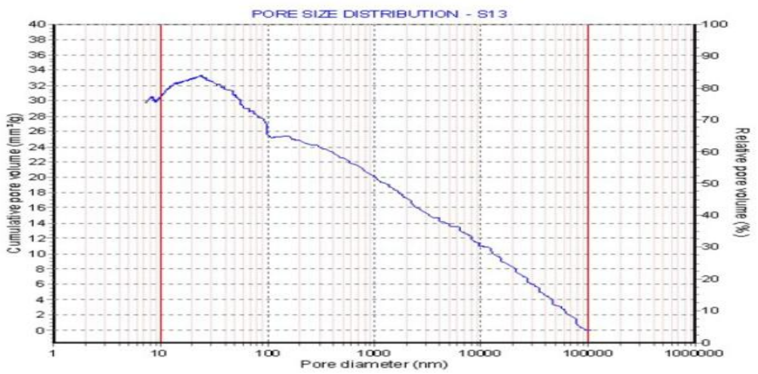


Figure 44: Pore size distribution for NS5CR25

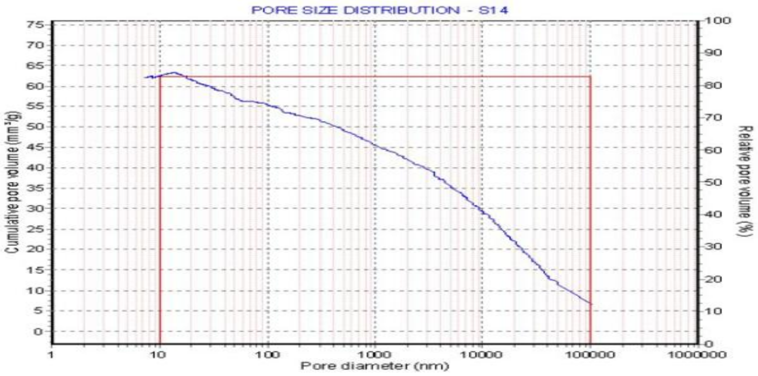


Figure 45: Pore size distribution for NS5CR50

From Table 13, the results showed that the total pore volume increases with the increasing percentage of crumb rubber replacement. The total pore volume is higher in mixture NS5 CR50 because of the replacement of fine aggregate with crumb rubber. The replacement of 50% crumb rubber is an outlier that has a total pore volume of 51.23mm^3/g. Crumb rubber tended to repel water and entraps air on the surface of the crumb rubber which led to the formation of air voids in the concrete. The presence of higher number of air voids increases the pore volume in the concrete. Higher percentage of crumb rubber replacement increases the number of air voids, resulting in increasing volume of pores. The pore distribution for Nano silica 3% has a gradually decreasing distribution of pore diameter. Higher pore volume in the pore size distribution represent that the mixture has higher porosity and permeability.

Table 13: Total pore volume for Nano silica 5%

Mixture		Total pore volume (mm^3/g)
NS5	CR0	1.86
	CR10	-1.63
	CR25	29.72
	CR50	61.99

4.2.1.2.Influence of Nano silica on rubbercrete

Figure 46, 47, 48, 49, 50, and 51 presented the graph of pore size distribution for crumb rubber replacement 0% with different percentage of Nano silica (0%-5%) and a control mixture which is NS0CR0. The pore diameter ranges from 10-100000nm in size. Table 14 below showed the total pore volume for the mixture.

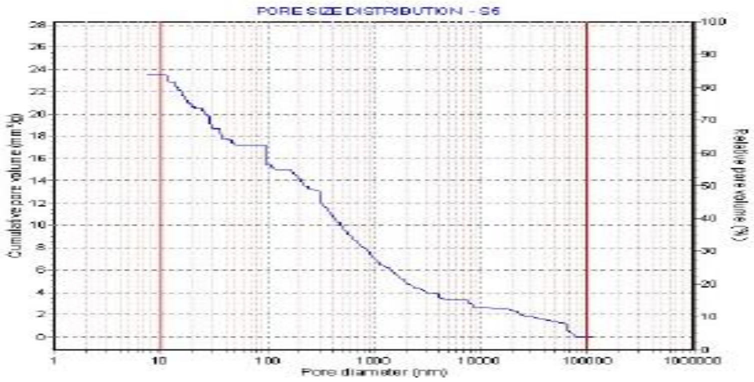


Figure 46: Pore size distribution for NS0CR0

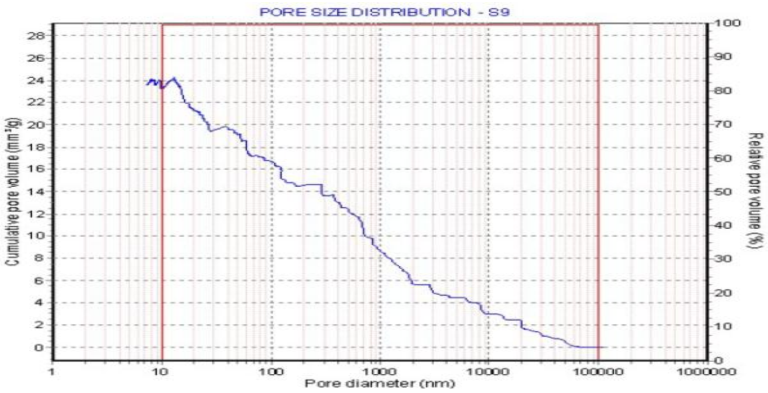


Figure 47: Pore size distribution for NS1 CR0

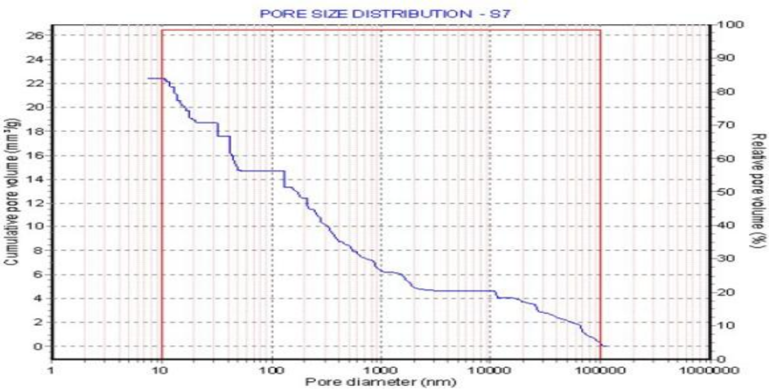


Figure 48: Pore size distribution for NS2CR0

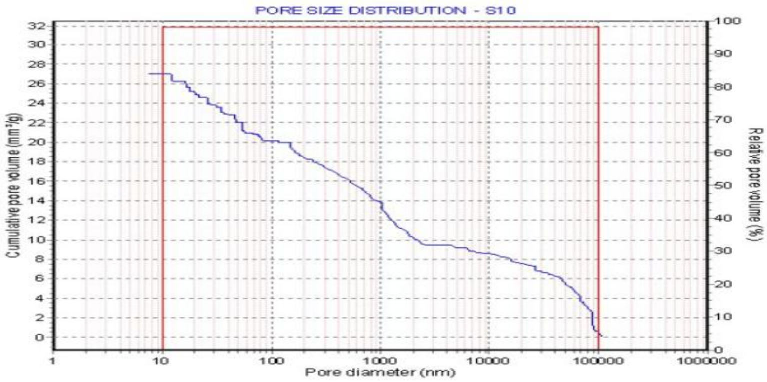


Figure 49: Pore size distribution for NS3CR0

Figure 50: Pore size distribution for NS4CR0

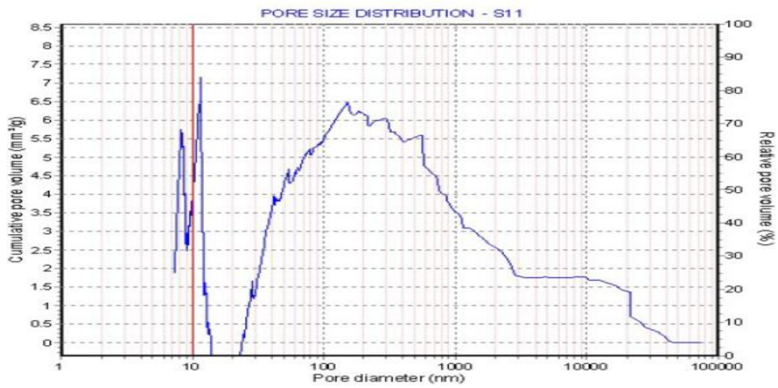


Figure 51: Pore size distribution for NS5CR0

From Table 14, the results showed that the total pore volume decreases with the increasing percentage of Nano silica. The total pore volume is lowest in mixture NS5 CR0 because of the addition of Nano silica. Nano silica acts as a filler and has pozzolanic reaction with calcium hydroxide to fill the air void caused by the presence of crumb rubber. Therefore, the pore structure is refined, together with the reduced of total pore volume.

Table 14: Total pore volume of Crumb rubber 0%

Mixture		Total pore volume (mm^3/g)
CR0	NS0	23.55
	NS1	23.53
	NS2	22.44
	NS3	21.91
	NS4	21.11
	NS5	1.86

Figure 52, 53, 54, 55, 56, and 57 presented the graph of pore size distribution for crumb rubber replacement 10% with different percentage of Nano silica (0%-5%) and a control mixture which is NS0CR0. The pore diameter ranges from 10-100000nm in size. Table 15 below showed the total pore volume for the mixture.

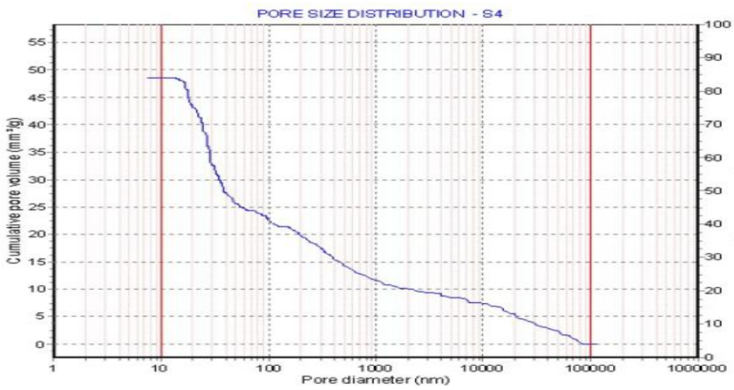


Figure 52: Pore size distribution for NS0CR10

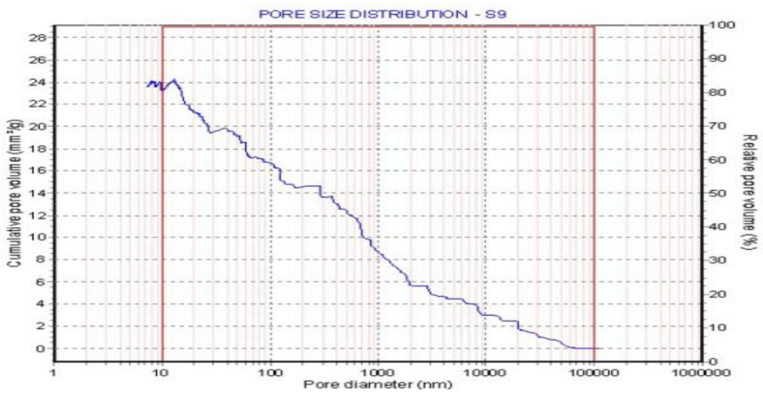


Figure 53: Pore size distribution for NS1CR10

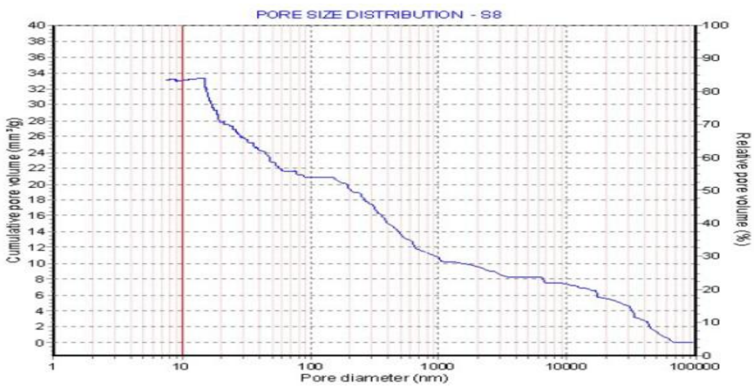


Figure 54: Pore size distribution for NS2CR10

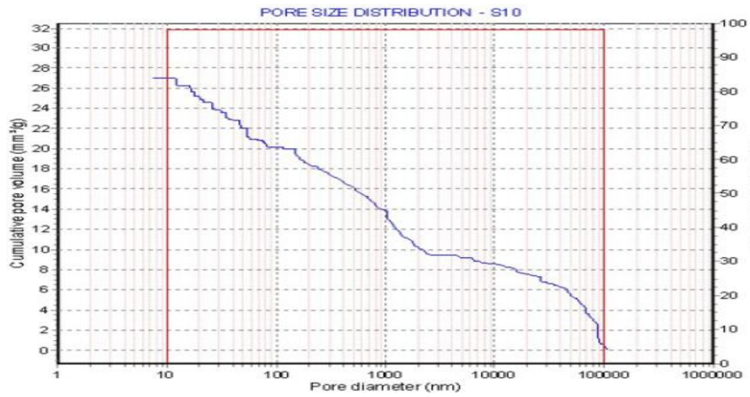


Figure 55: Pore size distribution for NS3CR10

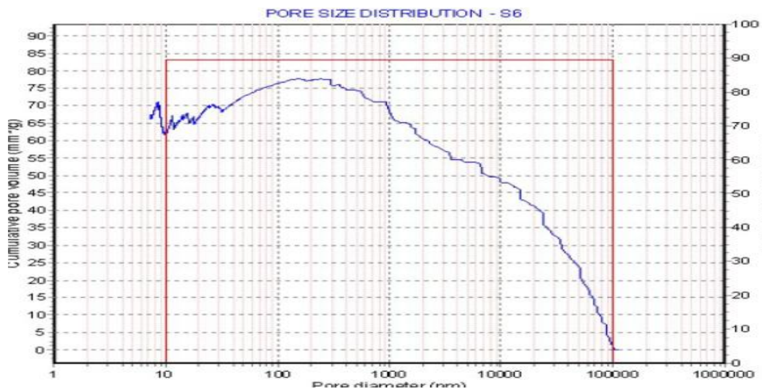


Figure 56: Pore size distribution for NS4CR10

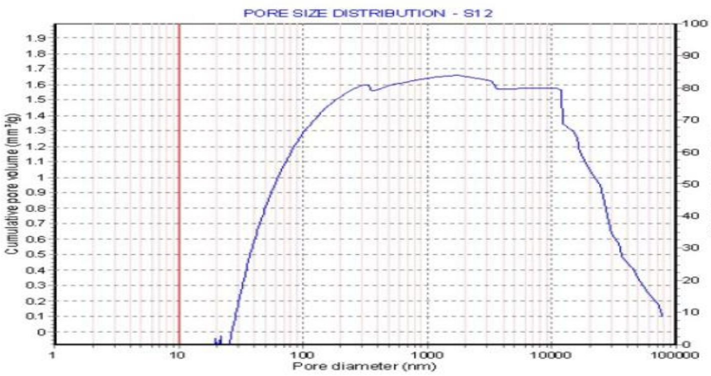


Figure 57: Pore size distribution for NS5CR10

Table 15: Total pore volume of Crumb rubber 10%

Mixture		Total pore volume (mm^3/g)
CR10	NS0	48.59
	NS1	44.23
	NS2	33.09
	NS3	27.05
	NS4	25.89
	NS5	-1.63

From Table 15, the results showed that the total pore volume decreases with the increasing percentage of Nano silica. The total pore volume is lowest in mixture NS5 CR10 because of the addition of Nano silica. Nano silica acts as a filler and has pozzolanic reaction with calcium hydroxide to fill the air void caused by the presence of crumb rubber. Therefore, the pore structure is refined, together with the reduced of total pore volume.

Figure 58, 59, 60, 61, 62, and 63 presented the graph of pore size distribution for crumb rubber replacement 25% with different percentage of Nano silica (0%-5%) and a control mixture which is NS0CR0. The pore diameter ranges from 10-100000nm in size. Table 16 below showed the total pore volume for the mixture.

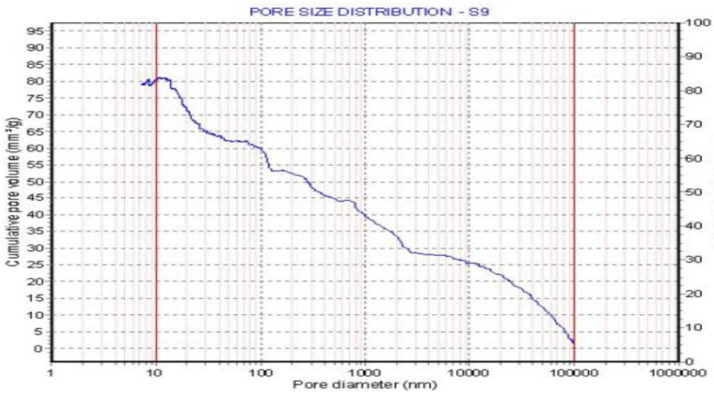


Figure 58: Pore size distribution for NS0CR25

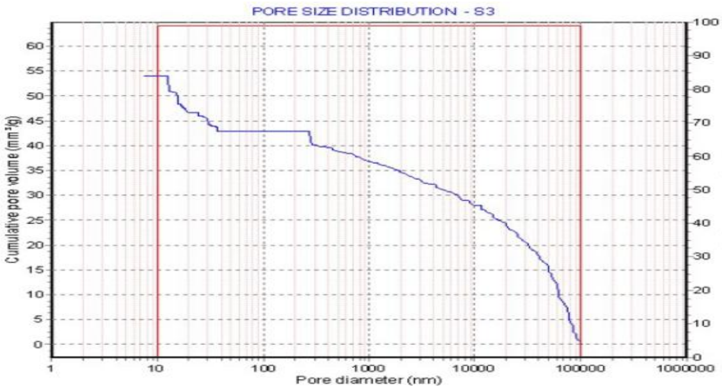


Figure 59: Pore size distribution for NS1CR25

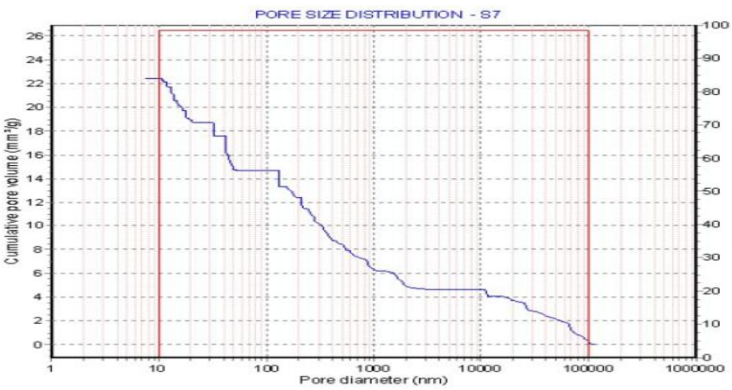


Figure 60: Pore size distribution for NS2CR25

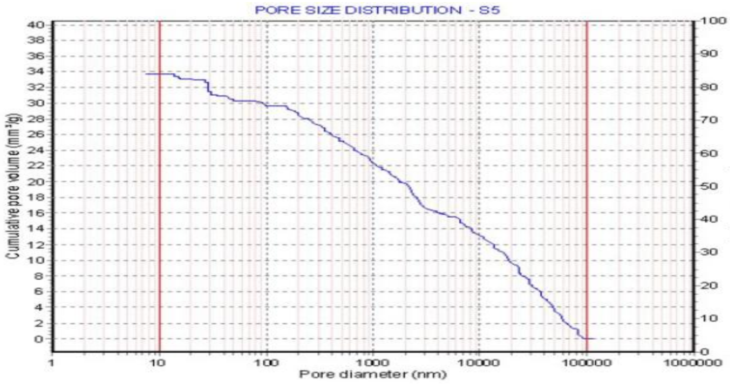


Figure 61: Pore size distribution for NS3CR25

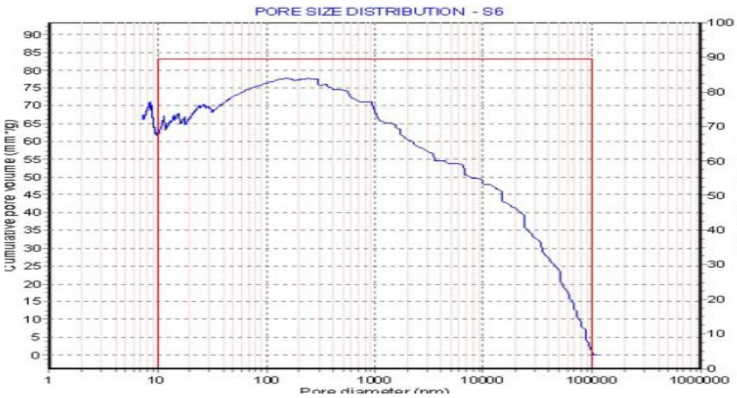


Figure 62: Pore size distribution for NS4CR25

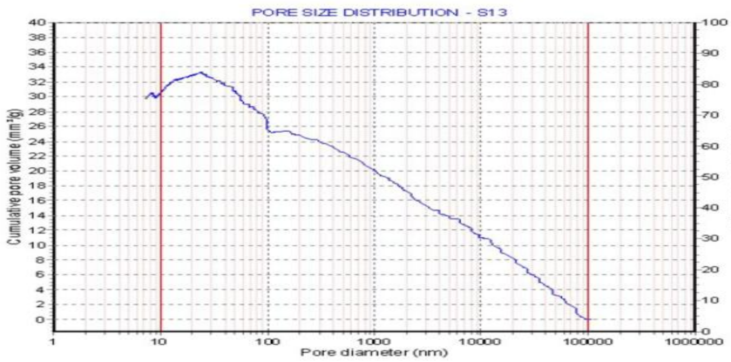


Figure 63: Pore size distribution for NS5CR25

From Table 16, the results showed that the total pore volume decreases with the increasing percentage of Nano silica. The total pore volume is lowest in mixture NS5 CR25 because of the addition of Nano silica. Nano silica acts as a filler and has pozzolanic reaction with calcium hydroxide to fill the air void caused by the presence of crumb rubber. Therefore, the pore structure is refined, together with the reduced of total pore volume.

Table 16: Total pore volume for crumb rubber 25%

Mixture		Total pore volume (mm^3/g)
CR25	NS0	79.1
	NS1	54
	NS2	50.73
	NS3	33.73
	NS4	33.49
	NS5	29.72

Figure 64, 65, 66, 67, 68, and 69 presented the graph of pore size distribution for crumb rubber replacement 50% with different percentage of Nano silica (0%-5%) and a control mixture which is NS0CR0. The pore diameter ranges from 10-100000nm in size. Table 17 below showed the total pore volume for the mixture.

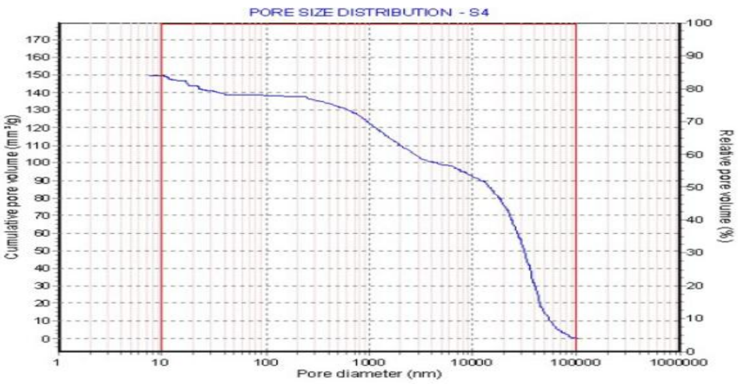


Figure 64: Pore size distribution for NS0CR50

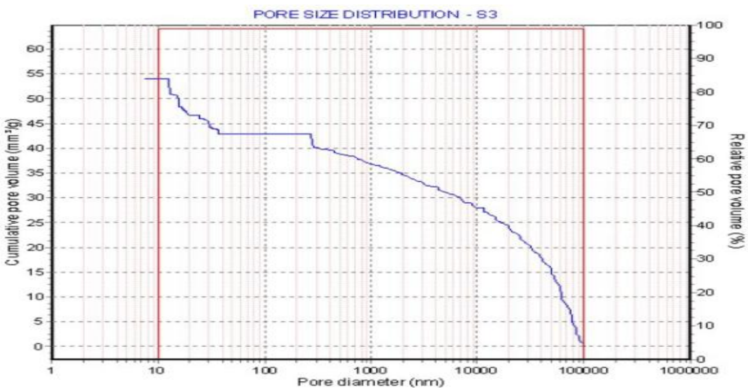


Figure 65: Pore size distribution for NS1CR50

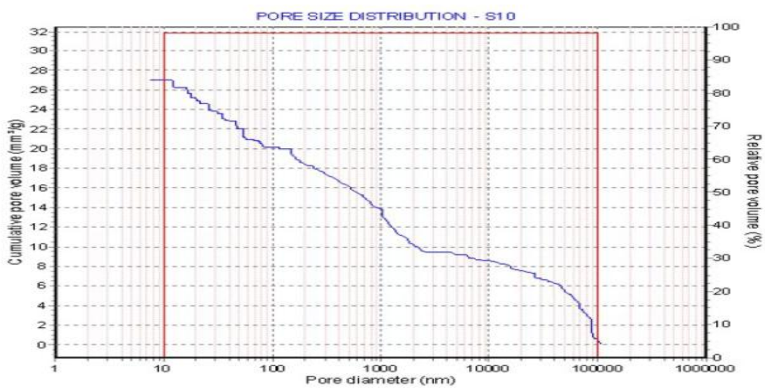


Figure 66: Pore size distribution for NS2CR50

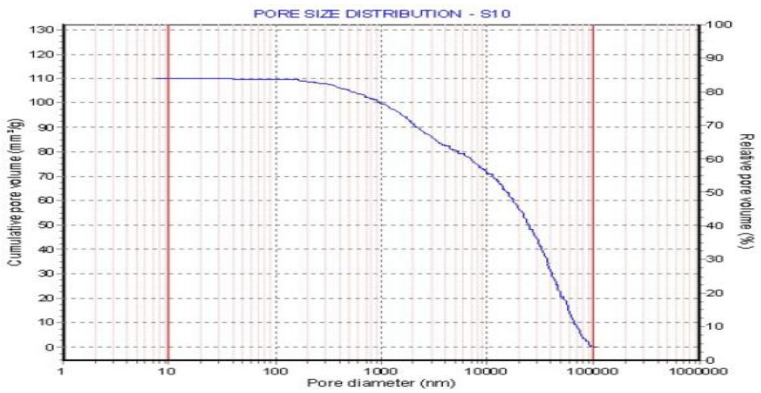


Figure 67: Pore size distribution for NS3 CR50

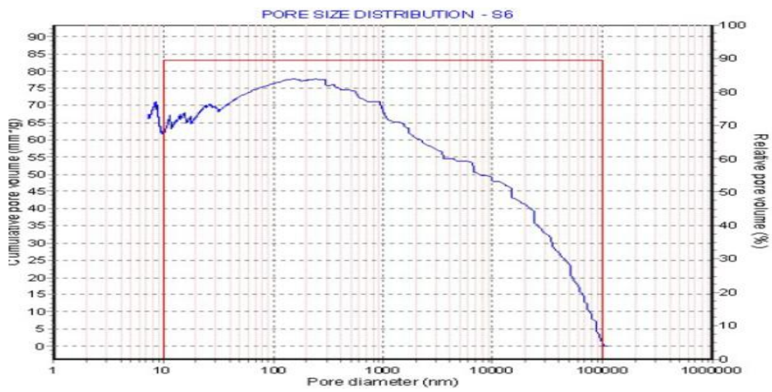


Figure 68: Pore size distribution for NS4CR50

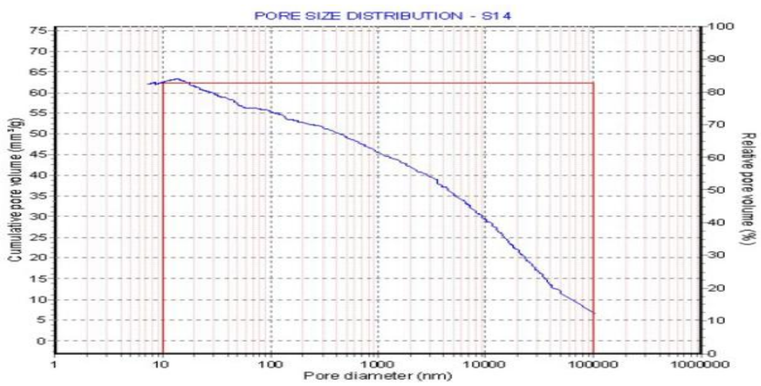


Figure 69: Pore size distribution for NS5CR50

From Table 17, the results showed that the total pore volume decreases with the increasing percentage of Nano silica. The total pore volume is lowest in mixture NS5 CR25 because of the addition of Nano silica. Nano silica acts as a filler and has pozzolanic reaction with calcium hydroxide to fill the air void caused by the presence of crumb rubber. Therefore, the pore structure is refined, together with the reduced of total pore volume.

Table 17: Total pore volume for crumb rubber 50%

Mixture		Total pore volume (mm^3/g)
CR50	NS0	149.62
	NS1	140.67
	NS2	132.38
	NS3	110.05
	NS4	67.37
	NS5	61.99

4.3. Field Emission Scanning Electron Microscope (FESEM)

FESEM test is conducted in order to have a clearer image on the interfacial transition zone and the bonding between the crumb rubbers and cement paste.

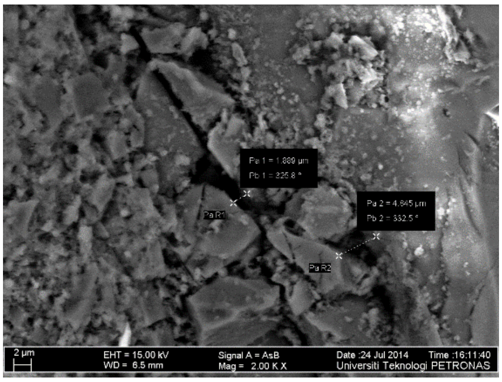


Figure 70: FESEM for NS0 CR0

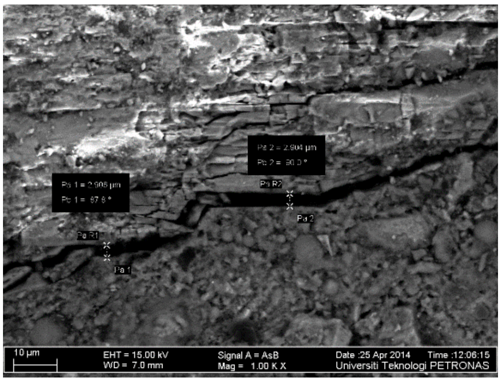


Figure 71: FESEM for NS0 CR10

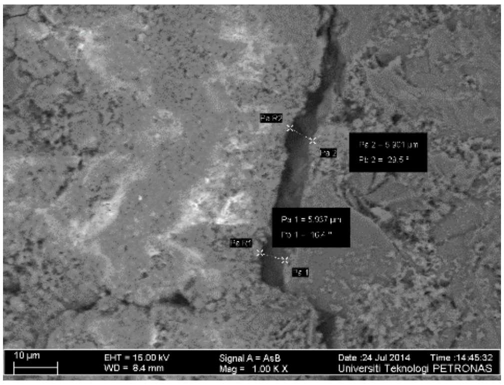


Figure 72: FESEM for NS0 CR25

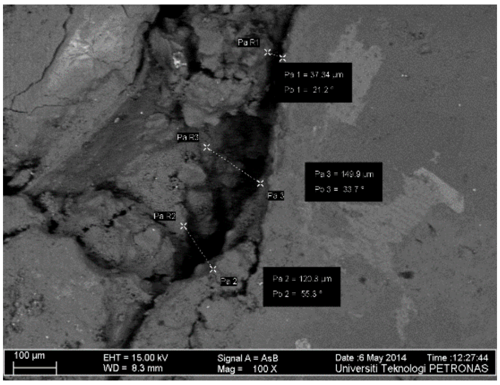


Figure 73: FESEM for NS0 CR50

From Figure 70-73, the interfacial transition zone between coarse aggregate and cement matrix is shown for Nano silica 0% with crumb rubber 0%, 10%, 25%, and 50%. NS0 CR0 illustrates a denser and uniform microstructure as compared to NS0 CR50. This is because crumb rubber repels water and entraps air on its surface which causes the formation of air voids in the rubbercrete. The formation of air voids in the rubbercrete reduce the adhesion between crumb rubber and cement paste which create weak bonding between crumb rubber and cement paste. The weak bonding between crumb rubber and cement paste reduce the durability and strength of the rubbercrete.

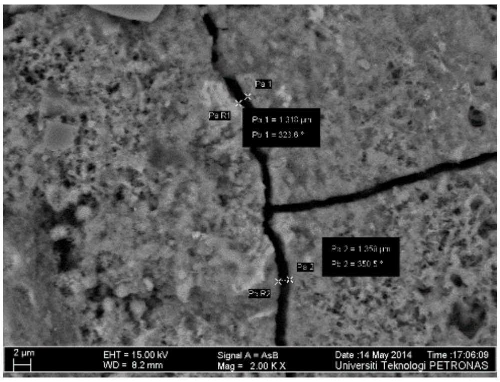


Figure 74: FESEM for NS1CR0

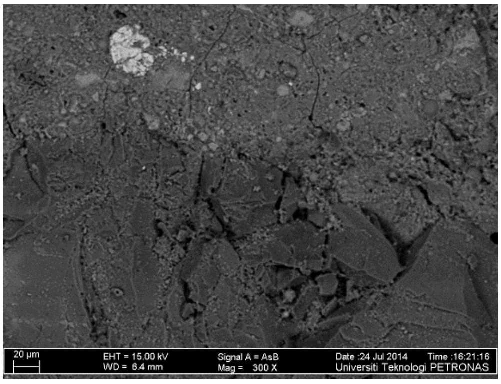


Figure 75: FESEM for NS1CR10

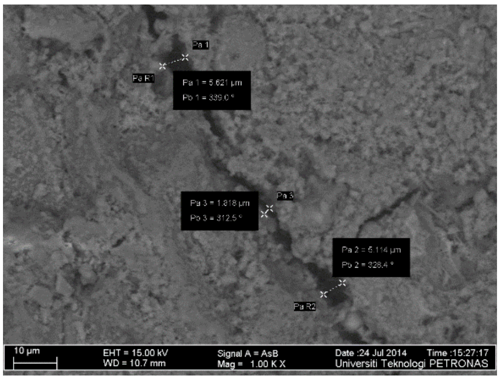


Figure 76: FESEM for NS1CR25

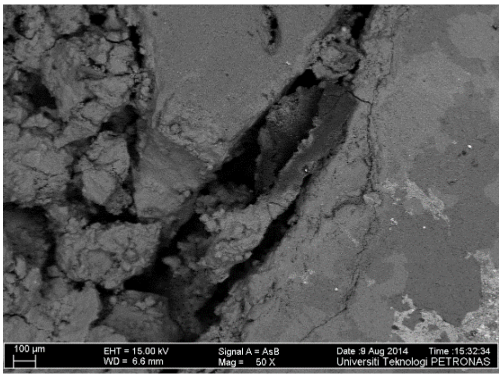


Figure 77: FESEM for NS1CR50

From Figure74 to 77, the interfacial transition zone between coarse aggregate and cement matrix is shown for Nano silica 1% with crumb rubber 0%, 10%, 25%, and 50%. NS0 CR0 illustrates a denser and uniform microstructure as compared to NS0 CR50. This is because crumb rubber repels water and entraps air on its surface which causes the formation of air voids in the rubbercrete. The formation of air voids in the rubbercrete reduce the adhesion between crumb rubber and cement paste which create weak bonding between crumb rubber and cement paste. The weak bonding between crumb rubber and cement paste reduce the durability and strength of the rubbercrete.

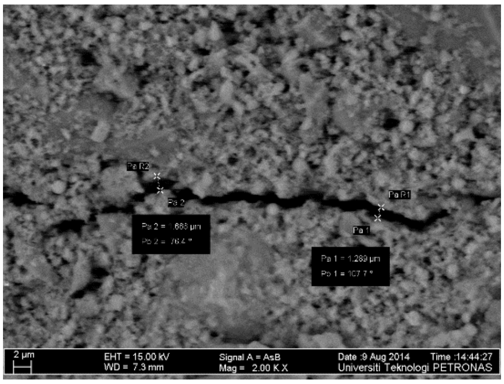


Figure 78: FESEM for NS2CR0

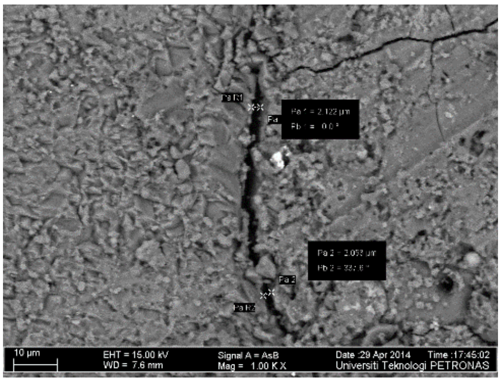


Figure 79: FESEM for NS2CR10

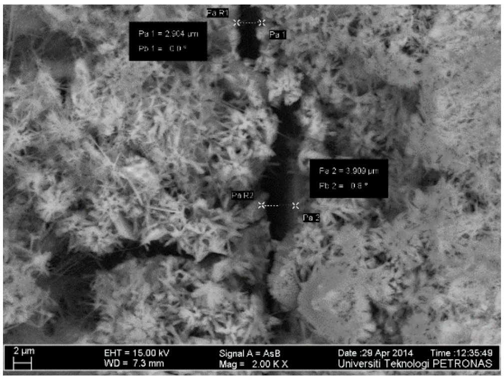


Figure 80: FESEM for NS2CR25

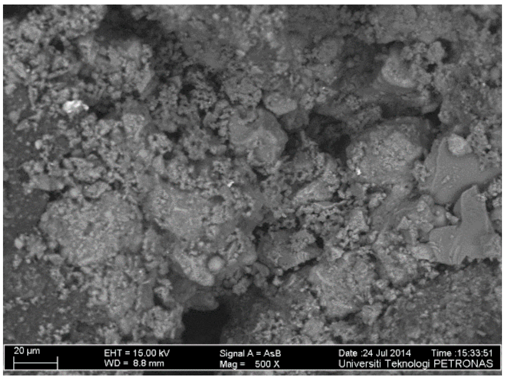


Figure 81: FESEM for NS2CR50

From Figure 78 to 81, the interfacial transition zone between coarse aggregate and cement matrix is shown for Nano silica 2% with crumb rubber 0%, 10%, 25%, and 50%. NS0 CR0 illustrates a denser and uniform microstructure as compared to NS0 CR50. This is because crumb rubber repels water and entraps air on its surface which causes the formation of air voids in the rubbercrete. The formation of air voids in the rubbercrete reduce the adhesion between crumb rubber and cement paste which create weak bonding between crumb rubber and cement paste. The weak bonding between crumb rubber and cement paste reduce the durability and strength of the rubbercrete.

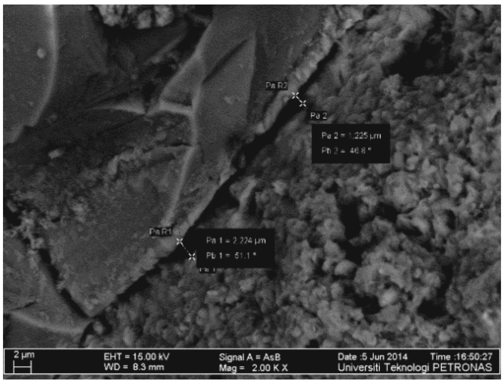


Figure 82: FESEM for NS3CR0

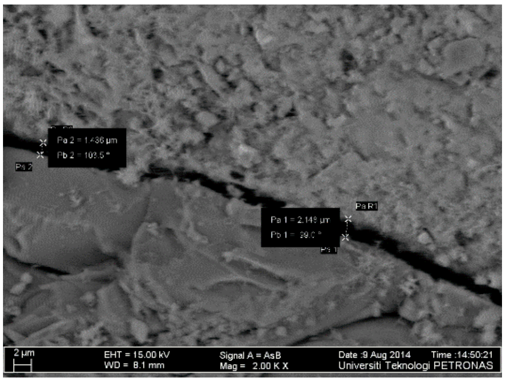


Figure 83: FESEM for NS3CR10

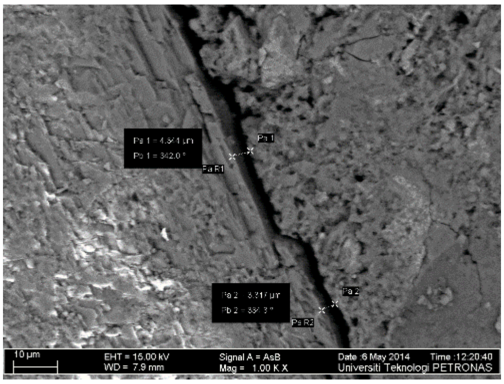


Figure 84: FESEM for NS3CR25

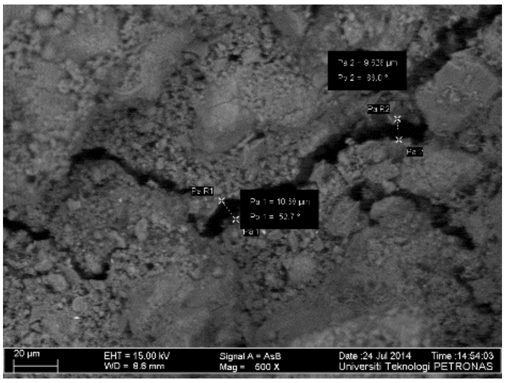


Figure 85: FESEM for NS3CR50

From Figure 82 to 85, the interfacial transition zone between coarse aggregate and cement matrix is shown for Nano silica 3% with crumb rubber 0%, 10%, 25%, and 50%. NS0 CR0 illustrates a denser and uniform microstructure as compared to NS0 CR50. This is because crumb rubber repels water and entraps air on its surface which causes the formation of air voids in the rubbercrete. The formation of air voids in the rubbercrete reduce the adhesion between crumb rubber and cement paste which create weak bonding between crumb rubber and cement paste. The weak bonding between crumb rubber and cement paste reduce the durability and strength of the rubbercrete.

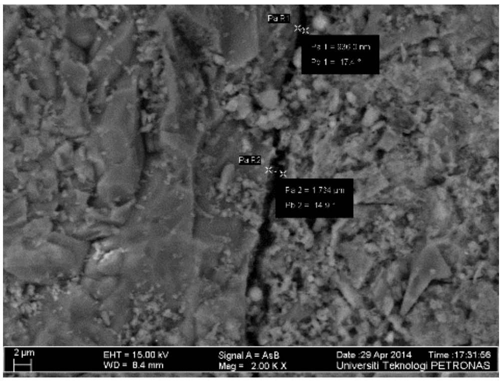


Figure 86: FESEM for NS4CR0

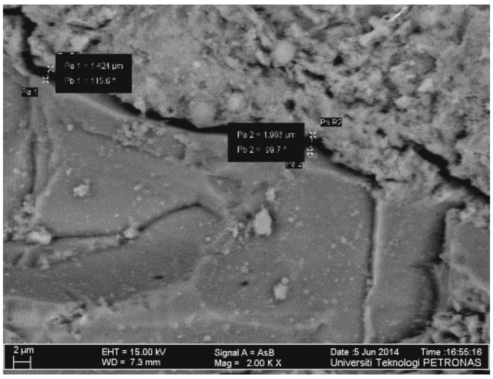


Figure 87: FESEM for NS4CR10

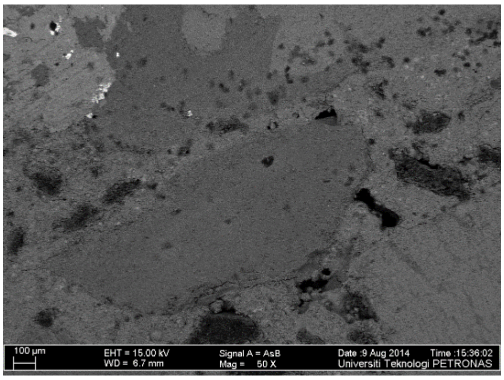


Figure 88: FESEM for NS4CR25

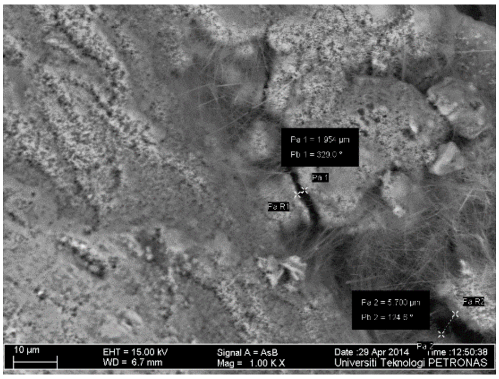


Figure 89: FESEM for NS4CR50

From Figure 86 to 89, the interfacial transition zone between coarse aggregate and cement matrix is shown for Nano silica 4% with crumb rubber 0%, 10%, 25%, and 50%. NS0 CR0 illustrates a denser and uniform microstructure as compared to NS0 CR50. This is because crumb rubber repels water and entraps air on its surface which causes the formation of air voids in the rubbercrete. The formation of air voids in the rubbercrete reduce the adhesion between crumb rubber and cement paste which create weak bonding between crumb rubber and cement paste. The weak bonding between crumb rubber and cement paste reduce the durability and strength of the rubbercrete.

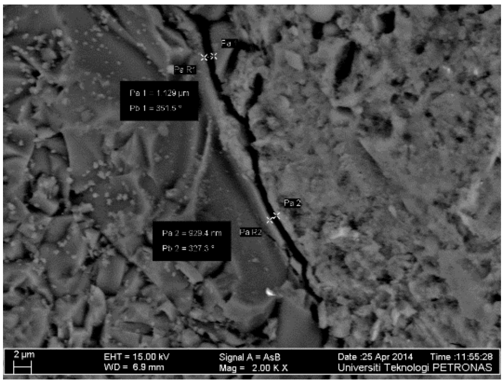


Figure 90: FESEM for NS5CR0

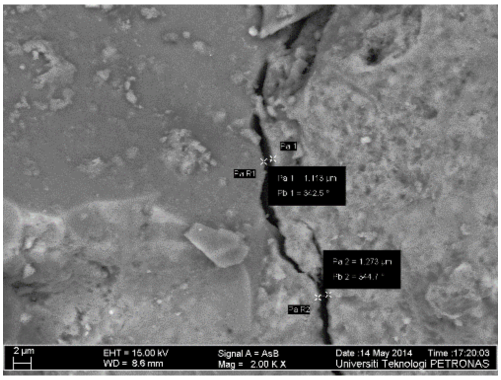


Figure 91: FESEM for NS5CR10

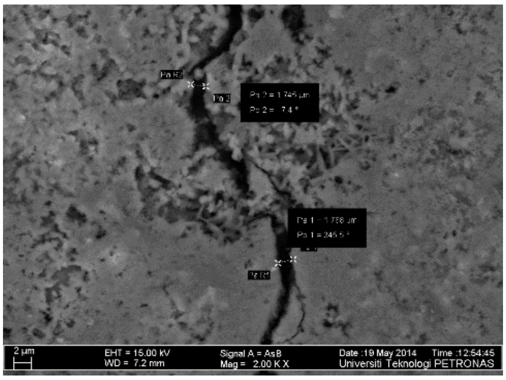


Figure 92: FESEM for NS5CR25

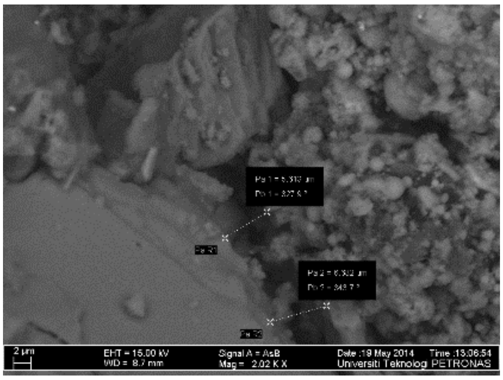


Figure 93: FESEM for NS5CR50

From Figure 90 to 93, the interfacial transition zone between coarse aggregate and cement matrix is shown for Nano silica 5% with crumb rubber 0%, 10%, 25%, and 50%. NS0 CR0 illustrates a denser and uniform microstructure as compared to NS0 CR50. This is because crumb rubber repels water and entraps air on its surface which causes the formation of air voids in the rubbercrete. The formation of air voids in the rubbercrete reduce the adhesion between crumb rubber and cement paste which create weak bonding between crumb rubber and cement paste. The weak bonding between crumb rubber and cement paste reduce the durability and strength of the rubbercrete.

Table 18 and Figure 94 showed the results for interfacial transition zone between coarse aggregate and cement matrix.

Table 18: Overall results for Interfacial Transition Zone (ITZ)

Percentage of Nano silica (%)	Percentage of Crumb Rubber (%)	CA & CP
0	0	1.9
	10	2.9
	25	5.9
	50	37.3
1	0	1.3
	10	2.2
	25	5.1
	50	25.0
2	0	1.3
	10	2.1
	25	3.9
	50	10.3
3	0	1.2
	10	1.4
	25	3.3
	50	9.6
4	0	0.9
	10	1.4
	25	2.0
	50	5.7
5	0	0.9
	10	1.1
	25	1.7
	50	5.6

From Figure 94, interfacial transition zone decreases with the increasing percentage of Nano silica. This clearly indicated that the incorporation of Nano silica in concrete has improved on the interfacial transition zone on the concrete and the bonding between coarse aggregate and cement matrix has significantly reduced. The filler effect of Nano silica reacts with calcium hydroxide produces more calcium silicate hydrate (C-S-H) gel to fill the air voids in concrete and even the small air voids in the concrete are omitted. The improvement in the microstructural of the concrete will enhance the performance and durability of the concrete as the rubbercrete has become denser and more compact.

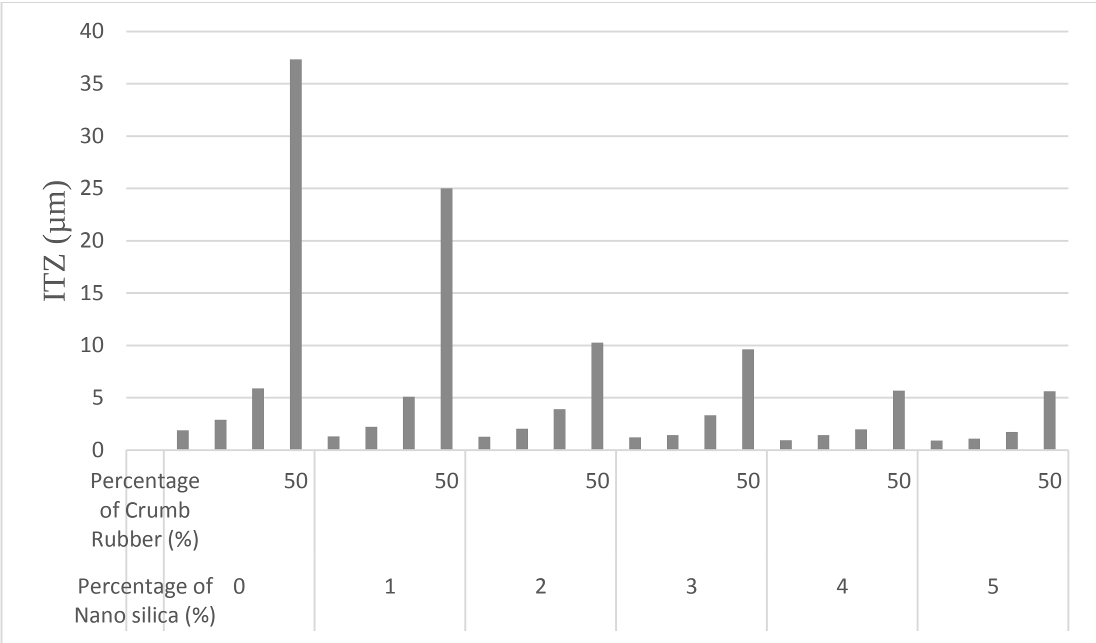


Figure 94: Graph represent the overall result for Interfacial Transition Zone (ITZ)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Crumb rubber concrete is a great invention in the civil engineering applications for construction industry as it promote greener environment. It exhibits numerous benefits as compared to conventional concrete. The only drawback for the crumb rubber concrete is the decreasing compressive strength with increasing percentage of Nano silica which is caused by the presence of interfacial transition zone that weakens the bonding between crumb rubber and cement concrete. In this report, several laboratory works are conducted to investigate the durability aspects of the crumb rubber concrete containing Nano silica. The pore structure of the crumb rubber concrete will be observed to identify the effects of Nano silica on the crumb rubber concrete. Consequently, mixture proportion with different percentage of crumb rubber and Nano silica is added to obtain the optimum performance of the crumb rubber concrete containing Nano silica. It has been found out that the crumb rubber concrete containing Nano silica improved the compressive strength, porosity and interfacial transition zone of the rubbercrete. The conclusion that is established from the research is:

- Crumb rubber concrete with Nano silica 5% establish a better compressive strength, porosity and interfacial transition zone as compared to the crumb rubber concrete with Nano silica from 0% to 4%.

- The porosity is improved after addition of Nano silica in crumb rubber concrete. Rubbercrete with Nano silica 5% and Crumb rubber 10% obtained 1.4%.

- The interfacial transition zone is reduced with the addition of Nano silica in crumb rubber concrete to 0.9µm for rubbercrete with Nano silica 5% and crumb rubber 0%.

The recommendation for the project is to attempt on the usage of colloidal Nano silica instead of powdery Nano silica for better and consistent results. This is because colloidal Nano silica can mix better with the mixture as compared to the powdery Nano silica and it can contribute the best to the result of the project.

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APPENDICES

Appendix 1: Mixture Proportion for S0F15 mix

Nano Silica 1% Crumb Rubber 0%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.3764	6.882
Crumb Rubber	0	0
Nano Silica	0.007199075	0.035995375
Water	0.232010226	1.16005113

Appendix 1.1. : Mixture proportion for NS1 CR0

Nano Silica 1% Crumb Rubber 10%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.23876	6.1938
Crumb Rubber	0.06768	0.3384
Nano Silica	0.007199075	0.035995375
Water	0.226413426	1.13206713

Appendix 1.2. : Mixture proportion for NS1 CR10

Nano Silica 1% Crumb Rubber 25%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.0323	5.1615
Crumb Rubber	0.1692	0.846
Nano Silica	0.007199075	0.035995375
Water	0.218018226	1.09009113

Appendix 1.3. : Mixture proportion for NS1 CR25

Nano Silica 1% Crumb Rubber 50%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	0.6882	3.441
Crumb Rubber	0.3384	1.692
Nano Silica	0.007199075	0.035995375
Water	0.204026226	1.02013113

Appendix 1.4. : Mixture proportion for NS1 CR50

Nano Silica 2% Crumb Rubber 0%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.3764	6.882
Crumb Rubber	0	0
Nano Silica	0.01439815	0.07199075
Water	0.232586152	1.16293076

Appendix 1.5. : Mixture proportion for NS2 CR0

Nano Silica 2% Crumb Rubber 10%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.23876	6.1938
Crumb Rubber	0.06768	0.3384
Nano Silica	0.01439815	0.07199075
Water	0.226989352	1.13494676

Appendix 1.6. : Mixture proportion for NS2 CR10

Nano Silica 2% Crumb Rubber 25%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.0323	5.1615
Crumb Rubber	0.1692	0.846
Nano Silica	0.01439815	0.07199075
Water	0.218594152	1.09297076

Appendix 1.7. : Mixture proportion for NS2 CR25

Nano Silica 2% Crumb Rubber 50%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	0.6882	3.441
Crumb Rubber	0.3384	1.692
Nano Silica	0.01439815	0.07199075
Water	0.204602152	1.02301076

Appendix 1.8. : Mixture proportion for NS2 CR50

Nano Silica 3% Crumb Rubber 0%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.3764	6.882
Crumb Rubber	0	0
Nano Silica	0.021597225	0.107986125
Water	0.233162078	1.16581039

Appendix 1.9. : Mixture proportion for NS3 CR0

Nano Silica 3% Crumb Rubber 10%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.23876	6.1938
Crumb Rubber	0.06768	0.3384
Nano Silica	0.021597225	0.107986125
Water	0.227565278	1.13782639

Appendix 1.10. : Mixture proportion for NS3 CR10

Nano Silica 3% Crumb Rubber 25%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.0323	5.1615
Crumb Rubber	0.1692	0.846
Nano Silica	0.021597225	0.107986125
Water	0.219170078	1.09585039

Appendix 1.11. : Mixture proportion for NS3 CR25

Nano Silica 3% Crumb Rubber 50%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	0.6882	3.441
Crumb Rubber	0.3384	1.692
Nano Silica	0.021597225	0.107986125
Water	0.205178078	1.02589039

Appendix 1.12. : Mixture proportion for NS3 CR50

Nano Silica 4% Crumb Rubber 0%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.3764	6.882
Crumb Rubber	0	0
Nano Silica	0.0287963	0.1439815
Water	0.233738004	1.16869002

Appendix 1.13. : Mixture proportion for NS4 CR0

Nano Silica 4% Crumb Rubber 10%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.23876	6.1938
Crumb Rubber	0.06768	0.3384
Nano Silica	0.0287963	0.1439815
Water	0.228141204	1.14070602

Appendix 1.14. : Mixture proportion for NS4 CR10

Nano Silica 4% Crumb Rubber 25%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.0323	5.1615
Crumb Rubber	0.1692	0.846
Nano Silica	0.0287963	0.1439815
Water	0.219746004	1.09873002

Appendix 1.15. : Mixture proportion for NS4 CR25

Nano Silica 4% Crumb Rubber 50%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	0.6882	3.441
Crumb Rubber	0.3384	1.692
Nano Silica	0.0287963	0.1439815
Water	0.205754004	1.02877002

Appendix 1.16. : Mixture proportion for NS4 CR50

Nano Silica 5% Crumb Rubber 0%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.3764	6.882
Crumb Rubber	0	0
Nano Silica	0.035995375	0.179976875
Water	0.23431393	1.17156965

Appendix 1.17. : Mixture proportion for NS5 CR0

Nano Silica 5% Crumb Rubber 10%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.23876	6.1938
Crumb Rubber	0.06768	0.3384
Nano Silica	0.035995375	0.179976875
Water	0.22871713	1.14358565

Appendix 1.18. : Mixture proportion for NS5 CR10

Nano Silica 5% Crumb Rubber 25%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	1.0323	5.1615
Crumb Rubber	0.1692	0.846
Nano Silica	0.035995375	0.179976875
Water	0.22032193	1.10160965

Appendix 1.19. : Mixture proportion for NS5 CR25

Nano Silica 5% Crumb Rubber 50%	per 1 mix(kg)	per 5 mix(kg)
Coarse Aggregate	0.688475	3.442375
Cement	0.7199075	3.5995375
Fly Ash	0.10814625	0.54073125
Sand	0.6882	3.441
Crumb Rubber	0.3384	1.692
Nano Silica	0.035995375	0.179976875
Water	0.20632993	1.03164965

Appendix 1.20. : Mixture proportion for NS5 CR50